THE UNIVERSITY OF ALBERTA

RURAL GROUNDWATER QUALITY IN ALBERTA

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DARCY A. FITZGERALD ©

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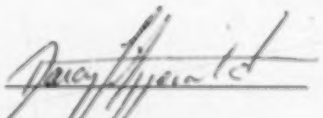

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled RURAL GROUNDWATER QUALITY IN ALBERTA submitted by DARCY A. FITZGERALD in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN WATER AND LAND RESOURCES.

Dr. D.S. Chanasyk (Supervisor)

Dr. M.A. Naeth

Dr. T.S. Veeman

Dr. M.J. Dudas

Date: December 18, 1998

Abstract

The purpose of evaluating the rural groundwater quality in Alberta through the Farmstead Water Quality Survey was (i) to determine if on-farm drinking water supplies derived from groundwater sources meet the Guidelines for Canadian Drinking Water Quality, and (ii) to assess the impact of anthropogenic practices and natural conditions on observed concentrations of nitrate, total coliform, and herbicide detections.

In total, 816 farms were surveyed in 1995-1996, 32% exceeded maximum acceptable concentrations, 92% exceeded the aesthetic objectives. Three percent of the wells had herbicide detections. Fourteen percent had detectable levels of total coliform (7% > 10 colonies/100 mL), and 6% had faecal coliform detections. Well age and depth did not significantly affect coliform or herbicide detection. While 6% exceeded 10 mg/L of nitrate, primarily in older, shallower, and dug wells.

This study has indicated concern for naturally occurring chemical contaminants, private distribution system contamination and general well construction parameters for specific groundwater quality contaminants in Alberta.

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Chapter 1. Overview Of Issues Relating To On-farm Drinking Water Quality From Groundwater Sources In Alberta

1.1 Introduction

The majority of Albertans live in large towns and cities where water quality is supported by billions of dollars in infrastructure which instills a great deal of confidence in its safety. The water provided by municipal treatment systems must meet standards set by provincial and federal guidelines (Guidelines for Canadian Drinking Water Quality (GCDWQ), Health Canada, 1996). This level of assurance affords urban residents a peace of mind about their water supply and a reduced burden in their daily activities.

In contrast, the more than 500,000 rural Albertans (Alberta Environmental Protection, 1986) who depend on private water supplies for their domestic drinking water needs do not have the same assurance of a high quality water source. The task of developing, maintaining, treating, and monitoring these private water supplies is primarily left to chance. On Alberta farms, where groundwater is the most common water source (Hess, 1981), a poor water quality supply can have a significant impact on both the health and economic well being of farm families.

Cherry et al. (1988), Miller et al. (1996), and Pupp et al. (1989) indicated that there are many areas within the prairie region of Canada where poor water quality can be attributed to the natural geology underlying these area. In southern Alberta, nitrate concentrations above the CDWQG, derived by the oxidation of exchangeable ammonium on soil particles, are common in shallow wells in sand seams within clay-rich glacial till (Cherry et al., 1988). Higher natural occurring nitrate levels in shallow aquifers in southern Alberta have also been reported by Johnston (1955), Hendry et al. (1984), Henry and Meneley (1993), and Rodvang and Wassenaar (1997). While some of the elevated nitrate levels may result from water moving through natural formations, the risk of nitrate contamination in shallow aquifers under heavily manured or fertilized fields has been documented (Chang and Entz, 1996;

Riddell and Rodvang, 1992; Rodvang and Wassenaar, 1997).

Local geology can also account for high concentrations of arsenic, fluoride, and selenium (Cherry et al., 1988 and Miller et al., 1996). Groundwater with these higher chemical concentrations represents a largely unassessed threat to the health of hundreds of thousands of Canadians whose domestic wells are not subjected to regular testing for these natural constituents (Cherry et al., 1988). Understanding the degree and levels at which this group is at risk can only be determined through monitoring programs or voluntary submission of water samples for quality analysis through private laboratories. Unfortunately, results from these laboratories are not available as the laboratories are bound by client confidentiality. Nor is it presently possible to access tax-funded public health water quality records due to existing confidentiality regulations.

Extensive groundwater quality surveys have been conducted in New Brunswick (Ecobichon et al., 1990), Nova Scotia (Moerman and Briggins, 1994), Ontario (Fleming, 1992; Frank et al., 1991; Rudolph et al., 1992), and Saskatchewan (Sheehan, 1998) as well as throughout most of the United States (Baker, 1990; Bauder et al., 1991; Kross et al., 1993; Mehnert et al., 1995; Sharpe et al., 1993; Sievers and Fulhage, 1992). Although the sample size, site selection methods, sampling procedures, and parameters analysed may have differed among these various water quality surveys, their foci were similar.

Some work documented the general geological factors that influence water quality in Alberta on a provincial wide basis (Pupp et al., 1989). However, little has been done to document the suitability of private farm water quality and its relationship to producer activities. The main focus of water quality research has been directed toward problems or site specific situations under a worst case scenario that may not be representative of levels of risk or factors associated with most of Alberta's private drinking supplies. The presence of contaminants in shallow water wells may not reflect contamination of the aquifer but rather the direct entrance of surface contaminants into the well. Similarly, shallow observation wells do not always reflect the conditions of an adjacent deeper private well. From a public

health perspective, sampling at the point of use reflects the quality of the consumed water and not necessarily the condition of the aquifer supply as contamination may occur due to a defective distribution system (Baker, 1990; Prior, 1994).

In some situations, naturally occurring levels of nitrate and trace metals can be found in groundwater in excess of the GCDWQ (Cherry et al., 1988; Miller et al., 1996; Pupp et al., 1989; and Rodvang and Wassenaar, 1997). However, individual farmers and landowners must also take the responsibility for managing the impact of their activities which can also adversely affect water quality (Bennett et al., 1992). The potential biological and chemical health risks from both anthropogenic and natural sources should be of concern to those individuals consuming untested or untreated water. Recognizing the potential for illness as well as understanding the interrelationships between human and animal activities, the natural conditions of the surrounding landscape, and the influence these factors may have on water quality is fundamental to having and preserving safe drinking water.

There is presently a heightened public recognition for the need to gather information on water quality and to provide this information and education to the public regarding water quality concerns (Birch, 1992; CAESA, 1998). However, some of the ambiguities related to the condition of on-farm water quality in Alberta can be addressed through benchmark monitoring, which in turn can help increase public awareness and pinpoint issues of concern. Therefore, determination of drinking water quality from groundwater sources and the causes of detected contaminants is of greatest concern.

As our society strives for sustainable agriculture systems which will indefinitely meet the demands for food and fibre at socially acceptable economic and environmental costs (Crosson, 1992), it often neglects to fully comprehend the potential health related problems that can be faced by the farm families who operate these systems. Those potential health as well as farm production problems can at times be related to the farm water quality which may be influenced by natural or anthropogenic conditions (Craun, 1985; Ecobichon et al., 1990; Geldreich, 1996; Steichen et al., 1988). By understanding and protecting the quality

of private domestic water supplies, there is an increased assurance of protecting the environmental component of the ecosystem farming operations exist in.

1.2 Determination of On-farm Water Quality

Hess (1981) estimated that 90% of Alberta's rural population relied on groundwater supplies, mainly due to the fact that it is neither physically nor economically possible to provide a common water supply to the majority of rural residents. The unfortunate point regarding private water sources used in Alberta often is the lack of testing and therefore knowledge of water quality. Without this basic knowledge, the health of those consuming the water as well as the general understanding of environmental changes caused by agricultural practices cannot be fully comprehended and/or mitigated.

The basic method of assessing the quality of groundwater accessed by rural residents has been to document the occurrence of contamination in domestic wells (Goss et al., 1997). This process, as indicated in the previous section, has been successful in helping us gain a better understanding of quality and inevitably the potential for human health and environmental concerns (Gosselin et al., 1997; Rudulph et al., 1992; Stievers and Fulhage, 1992). Therefore, it is the primary objective of this project to document the quality of a representative number of Alberta on-farm drinking water supplies derived from groundwater sources to determine if they meet the GCDWQ and provide a benchmark database for future studies. This benchmark database is to be provided through the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement's Farmstead Water Quality Survey (FWQS).

1.3 Evaluation of Factors Affecting Water Quality

Farm practices and site conditions (Burkart and Kolpin, 1993; Frank et al., 1987; Freeze and Cherry, 1979; Goss et al., 1997; Henry and Meneley, 1993; Rodvang et al., 1992; Steichen et al., 1988) influence the quality of groundwater. The contaminants of water wells of most

interest have been nitrates, bacteria, and pesticides. Determining if these three contaminants are indicative of water quality contamination due to specific natural or anthropogenic factors has been an important part of many other studies (Exner and Spalding, 1985; Madison and Brunett, 1985; Rudulph et al., 1992; Sharpe et al., 1993). As well, more specific impacts have been linked to agriculture by Chang and Entz (1996), Miller et al. (1996), Olson and Bennett (1998), and Riddle and Rodvang (1992) under specific conditions or in specific regions of the province. As such, a key component of this project is to identify, on a province basis, conditions and practices which influence the water quality of the farm water supplies analysed through the FWQS. The potential to identify significant differences among various categories of water quality parameters and anthropogenic practice may help to address cause and effect relationships.

1.4 Conclusions

Water is one of the most important inputs to all farming operations; however, the output effects that farming operations have on the environmental component of water quality is often a concern. Consequently, Alberta's on-farm drinking water quality is uncertain because of a lack of monitoring and interpretation. The information represented in this paper is not intended to represent an exhaustive study on the quality of groundwater throughout rural Alberta. But rather, the study is to provide general interpretations of the drinking water quality trends encountered and possible explanation for those concentrations observed in relation to both natural and anthropogenic effects.

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Chapter 2. Farm Well Water Quality In Alberta

2.1 Introduction

On-farm water quality surveys have been conducted in Ontario (Fleming, 1992; Frank et al., 1991; Goss et al., 1997), Nova Scotia (Moerman and Briggins, 1994) and throughout most of the United States (Baker, 1990; Bauder et al., 1991; Kross et al., 1993; Mehnert et al., 1995; Sharpe et al., 1993; Sievers and Fulhage, 1992). The trend from these surveys was for higher nitrate levels in older, shallow water wells without a significant correlation to bacteria detections. The percentage of herbicide detections was variable and dependent on the type and usage of any particular herbicide; however, most of the above surveys concluded that point source contamination rather than wide spread non-point sources was more identifiably the cause. Although the sample size, site selection methods, sampling procedures, and parameters analysed may have differed among these various water quality surveys, their focus was similar. The primary focus has been on a few specific water quality parameters such as nitrate, coliform bacteria, or pesticides, all of which provide a comparison for the Farmstead Water Quality Survey (FWQS) data.

In Alberta, groundwater is used by approximately 26% of the population of which roughly 440,000 private domestic users make up 72% of the total (Pupp et al., 1989). Statistics Canada (1991) reported a total population of 2,545,550 in Alberta and a farm population of 177,185. The majority of Alberta's farm population accesses groundwater supplies for domestic use with only a smaller portion of the population using purchased hauled or treated pipeline supplies and privately treated or untreated surface water supplies. While most of the farm population in Alberta utilizes groundwater via private wells, little information exists on the quality of these sources. The overall responsibility for ensuring the safety and testing the quality of these water supplies is left to the individual user as is the situation in the rest of Canada.

Several sources of information on water quality exist in Alberta. In the past, rural water supply records in Alberta had been collected through local regional health units. However, these records were not kept in a central electronic form until recently and those that are currently in electronic form are not available due to doctor-patient confidentiality. In most cases, these records represent problem water supplies which required testing and thus would not be considered a representative sampling of water supplies. Water analyses performed through private sector laboratories were also unavailable as client confidentiality was a concern. Another source of information was a database of 10,000 water supply records maintained by Alberta Agriculture, Food and Rural Development; unfortunately, these records are also viewed as biassed as they too would likely reflect problem water supplies and had been tested to answer specific treatment or health related concerns which were not documented.

Consequently, the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement, a five-year federal-provincial research initiative, funded the FWQS to conduct a comprehensive water quality survey of on-farm water wells in Alberta. The goal of the FWQS was to test on-farm groundwater supplies on a provincial basis to provide benchmark data to determine the suitability of domestic drinking water usage based on the Guidelines for Canadian Drinking Water Quality (GCDWQ) (Health Canada, 1996). Water samples from 820 farm sites were collected and tested for 48 parameters to determine the quality of the water supplies and possible linkages to primary agriculture.

The FWQS data were evaluated to determine if the quality of Alberta's on-farm water derived from groundwater supplies met the GCDWQ. Where concentrations were above acceptable levels, the laboratory results, local geology and soils information, and data collected through an associated FWQS questionnaire should be useful in identifying possible anthropogenic related factors which may have contributed to the reported concentrations.

2.2 Materials and Methods

2.2.1 Experimental Process

2.2.1.1 Pilot Project

A pilot project was initiated in 1994 to define methods and logistic problems before commencing the 1995 provincial FWQS study. In the pilot study sites, three geographically and agronomically different municipalities were chosen: the County of Lethbridge in southern Alberta, where irrigated and intensive livestock agriculture predominate and farms make use of water wells and irrigation water stored in dugouts (farm ponds); the County of Red Deer located in south-central Alberta, where dryland mixed farming operations make use of groundwater; and the Municipal District of Smoky River, located in northwestern Alberta, where large dryland grain farms using surface runoff dugouts are common. A total of 99 sites were surveyed in the County of Lethbridge, 51 in the County of Red Deer, and 40 in the Municipal District of Smoky River (Figure 2.1). The number of sites sampled within each municipality represented a greater number of sites than would be utilized for the provincial study. These larger numbers would allow for better statistical use of the data in the early stages of the project as the focus of the pilot was at a municipal rather than a regional or provincial level.

Each municipality was divided into four equal quadrants. An in-house software program was used by Agriculture and Agri-Food Canada statisticians to randomly generate legal land locations within each of the quadrants for potential farm sites to sample. Land owners were identified using municipal land title maps and contacted to determine if a farm building site with a water source (preferably domestic supply) existed at the selected site location. If this initial criterion of a farm building site with a water source was not satisfied, the next randomly generated location was checked until the desired number of sites had been located. In each case an equal number of sites were chosen from within each of the quadrants of each municipality. When all the sites were identified, trained sampling teams arranged to sample the water source. The untreated water samples were collected from the kitchen tap; however,

if that was impossible samples were collected from the most convenient point available. The sampling teams also administered a 6 page questionnaire when the water samples were collected.

The water samples collected at each site were shipped daily by courier to the appropriate Laboratory: Provincial Laboratory of Public Health (chemical, trace metal and microbiological samples) and Enviro-Test Laboratories (herbicide samples) both located in Edmonton, Alberta (Figure 2.2). The results were sent back to the participating farm cooperators via their local Public Health Unit Inspector. The questionnaire data and sample results were entered into a Paradox database software program for statistical analysis. Follow-up to the pilot project provided sample team feedback on logistics as well as refinements to the questionnaire before proceeding with the provincial study.

2.2.1.2 Farmstead Water Quality Survey

Site selection for the provincial study was based on the number of farms (Statistics Canada, 1991) located in each municipality (Appendix A.1) with a minimum sample size of 10 sites and a maximum of 20 sites from any one municipality (Figure 2.3). These sample sizes were based on a 95% confidence level (Allison and Neilson, 1994) and the constraints of the project budget. This provincial study, the FWQS, examined approximately 820 sites with the understanding that in areas of the province where water wells are not commonly used, fewer sites may be available for sampling. The sites within the municipalities were randomly generated from listings from producer programs (Alberta Farm Fuel Rebate Program, Alberta Crow Benefit Offset Program, Alberta Farm Fertilizer Rebate Program, and Alberta Feed-Grain Subsidy Program) administered by Alberta Agriculture, Food and Rural Development. In some situations, data from Alberta Environmental Protection's Groundwater Information Database were used to help identify farm sites within municipalities with small populations.

Site selection lists which provided potential participant names, legal land locations, addresses, and phone numbers on a municipal basis were supplied to sampling teams. Each list contained approximately three times as many sites as required to accommodate incidences of poor response or inappropriate site characteristics. The sampling teams contacted the participants by telephone and arranged to collect water samples and administer a questionnaire. At each site, water samples were collected for chemical, trace metal, herbicide, and microbiological analyses along with details of the farm site layout. The distances and locations of buildings, septic systems, fuel storage, farm operations, and general topography relative to the water well were recorded on a sketch of the site to provide additional information on the site if water quality problems were encountered.

The water samples collected at each site were individually documented and labelled with unique identification numbers and shipped by a courier within 24 h to laboratories for analysis. The results obtained from the laboratories were returned to the participants via their local Public Health Inspector. Along with laboratory results, Health Inspectors provided participants with specific information related to the water quality parameters analysed. For these sites with initial results that indicated water problems, re-sampling ensured there were no sample collection or laboratory errors.

2.2.2 Questionnaire

A seven-page questionnaire consisting of 94 individual questions with space for a sketch of the farm site was developed from the pilot questionnaire tested the previous year, along with information provided through staff from Alberta Agriculture, Food and Rural Development (AAFRD), Prairie Farm Rehabilitation Administration (PFRA), and Alberta Health. Information related to type of operation, building and operational setbacks from the water well, some construction details such as depth, diameter and age of the well, water treatment related information on usage and performance, and personal perceptions on environmental issues were gathered through the questionnaire (Appendix B.1). To increase the confidence

level of the questionnaire, it was administered by trained staff from AAFRD and PFRA.

2.2.3 Sampling Protocol

To enhance confidence in the sampling technique, a one-day workshop was held to train sample teams on proper sampling protocol, as outlined by team members from public health. The sample teams, as a group, completed the questionnaire during the workshop to standardize the method of collecting questionnaire data. It was believed that this process would heighten the understanding of the questions while standardizing the method of administering the questionnaire; thereby, reducing the potential bias of the sample teams. It was also believed that water sampling and questionnaire administration by a selected group of trained individuals (sample team members) would reduce sample errors.

Water samples were collected, as specified in the preceding analysis section, from the kitchen tap or in cases where treatment was present, at a location (tap) which bypassed treatment. The water samples obtained at the end of the distribution system do not reflect the true conditions of the groundwater as the well, pipes, connections, and facet may contribute to the overall chemical composition of the water quality. Therefore, the samples were collected after running water for 3 to 5 minutes to help decrease some of these potential chemical contaminants. The collected samples were then stored in coolers with ice packs. At several locations duplicate sampling was performed to assess variability due to sampling protocol and/or laboratory techniques.

Four groups of tests were performed on the water samples: routine chemistry, trace metal, microbiological, and selective herbicide. The routine chemistry analysis was used to determine if the water was drinkable (potable); the trace metals analysis was used to determine if there were any trace metals contaminating the water; the microbiological analysis was used to determine the presence of potentially harmful bacteria, and the herbicide analysis was used to detect the presence of eight selected herbicides.

The routine chemistry analysis used in this study measured the concentration of bicarbonate, calcium carbonate, chloride, fluoride, iron, magnesium, nitrate+ nitrite, potassium, sodium and sulphate, in addition to alkalinity, conductivity, hardness, pH, and the amount of dissolved solids. The trace metal analysis included: aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, strontium, titanium, thallium, uranium, vanadium, and zinc. The microbiological analysis, performed by the Alberta Provincial Laboratory for Public Health, tested the water samples for both total and faecal coliform bacteria which are an indicator organism for more harmful organisms. Finally, the herbicide analysis consisted of eight herbicides: Dicamba, MCPA, 2,4-D, Bromoxynil, Triallate, Triflurilin, Diclofop-methyl, and Fenoaprop.

2.2.4 Chemical Analysis

Water samples were collected in 500-mL PET500® (polyethylene terephthalate) sample bottles (System Plus, New Hamburg, ON). All samples were labelled for routine chemical analysis and shipped to the Provincial Laboratory of Public Health for delivery to the Capital Health Authority's Trace Element/Environmental Toxicology Laboratory at the University of Alberta Hospital in Edmonton, Alberta.

The samples were thoroughly mixed prior to aliquots being taken for the routine analyses. All chemical parameters were determined using modified American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater protocols (Audette, 1996).

Electrical conductivity, pH and fluoride concentrations were determined using radiometer conductivity specific ion electrodes employing a Radiometer VIT90 autotitrator system equipped with a 40-sample SAC90 auto-sampler, a CDM 80 conductivity meter, a ABU93

25-mL triburette (for the TISAB delivery) and the TitraLab software (Audette, 1996).

All cation analyses were performed using air/acetylene flame atomic absorption spectroscopy protocols on a Perkin Elmer Z5000 Flame Atomic Absorption Spectrophotometer equipped with a flow spoiler burner chamber and an AS40 auto-sampler. Samples were analysed for sodium, potassium, calcium, and magnesium. The calcium and magnesium aliquots contained a final concentration of 0.24 N HCl and 2% La (as $LaNO_3$) to eliminate interferences from varying concentrations of carbonate, bicarbonate and sulphate. Samples aliquoted for iron analysis were acidified with concentrated trace metal free HNO_3 to a final concentration of 1% HNO_3 to dissolve any precipitated iron.

The anion quantitations were performed on a Roche COBAS FARA autoanalyzer for chloride (ferricyanide method), nitrate+nitrite-N (hydrazine reduction method), sulphate (turbidimetric method), and alkalinity (autotitration method). Samples with pH > 8.3 were manually titrated employing a pH meter to a pH of 8.3 to assist in the proper calculation of carbonate, bicarbonate, and hydroxide concentrations. Total dissolved solids and ion balances were calculated from the analytical results.

The Certificate of Chemical Analysis report format forwarded to the Health Units for distribution to survey participants is given in Appendix B.2.

2.2.5 Trace Metals Analysis

Water samples were collected in 500-mL PET500^R (polyethylene terephthalate) trace metal free sample bottles (System Plus, New Hamburg, ON). After 500 mL of water were collected, the samples were preserved with 5 mL of trace metal free nitric acid, 70% (Eagle Picher 5 mL ampule - NA-6166-1EP2). All samples were properly labelled for trace metal analysis and shipped to the Provincial Laboratory of Public Health for delivery to the Capital Health Authority's Trace Element/Environmental Toxicology Laboratory at the University

of Alberta Hospital in Edmonton.

Samples were stored at 4 °C prior to analysis. Samples and standards were prepared in a trace metal free (TMF), positive pressure, hepafiltered room employing Eppendorff pipettes/ tips and Sarsted sample tubes. SPEX^R Certified Ultra-pure single element standards were employed for the preparation of all mixed aqueous calibration standards, internal standards, and quality control samples. All standards were prepared by weight in TMF Nalgene bottles, acidified with TMF HNO_3 acid and diluted to appropriate weight with Barnstead 18 Megohm-cm TMF water. SEASTAR^R TMF HNO_3 acid was used throughout (Audette, 1996).

The analyses were conducted in a separate TMF, positive pressure, hepafiltered room employing a PE-SCIEX Elan 5000A or Elan 6000 Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) operating in the quantitative mode with internal standardization. All samples contained a mixed internal standard consisting of ^{45}Sc, ^{89}Y, ^{103}Rh, and ^{181}Ta. The analyses for 23 trace metals were performed using a modified Ontario Ministry of Environment DWATER protocol (Determination of Trace Metals in potable waters by ICP-MS). The ICP-MS method employed was also consistent with the principles outlined in the US-EPA Method 200.8, Revision 5.4, 1994 protocol (Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry) and Method 6020, 1992 (Inductively Coupled Plasma - Mass Spectrometry).

The Certificate of Chemical Analysis report format forwarded to the Health Units for distribution to survey participants is given in Appendix B.3.

All routine chemistry and trace metal analytical procedures adhered to stringent in-house quality control (QC) protocols (typically 15-25% QC samples/unknowns). The coefficient of variation (SD / Mean • 100) for the routine analytes was between 0.2 and 4% while the coefficient of variation for the trace metals analytes was between 1 and 3%. In addition, the

laboratory successfully passed two external Proficiency Testing (PT) programs for all the parameters during the study. The first PT program was the bi-annual Alberta Water Analyst Committee PT program (20-30 Alberta water laboratories) and the second was the Analytical Product Group's Proficiency Environmental Testing Program (>250 North American laboratories) on a quarterly basis. Both PT programs meet the ISO Guide 43, 1996 Proficiency Testing Program protocols and employ z-scores for performance evaluations (Audette, 1996).

2.2.6 Microbiological Analysis

Pathogenic microorganisms that can occur in water include bacteria, enteric viruses, and protozoa. Because it is not practical to monitor all pathogens in drinking water, microbiological guidelines are based on detection of "indicator organisms". The Coliform group of bacteria is used as an indicator of the suitability of water for drinking or other purposes (Health Canada, 1996). While these bacteria serve as a good indicator of the presence of pathogenic bacteria, they are not as reliable in indicating the presence of some protozoa such as *Giardia* or *Cryptosporidium* or the presence of some viruses.

The maximum acceptable concentration (MAC) for total coliform in drinking water is less than 10 organisms detectable per 100 mL (Health Canada, 1996). However, because coliform are not uniformly distributed in water, if up to 10 total coliform organisms per 100 mL are detected, the water should be re-sampled. If the presence of coliform is reconfirmed, the cause should be determined and corrective action taken. Ideally, coliform bacteria should not be present in well water because these organisms require a nutrient source to survive, and are generally associated with plant and animal life processes that do not occur in deep wells.

The presence of coliform (total and faecal) bacteria was determined by either membrane filtration or by multiple tube fermentation, followed by selective media culture. Analysis was performed using modified American Public Health Association (APHA) Standard

Methods for the Examination of Water and Wastewater protocols (Ashton, 1996). Water samples were collected in sterile 250-mL polyethylene sample bottles containing sodium thiosulphate. The samples were shipped at approximately 5 °C and received by the Provincial Laboratory of Public Health, at the University of Alberta Hospitals in Edmonton within 24 h of sampling. Samples received for analyses between 24 h and 48 h after collection were accepted but microbiological growth was suspect to contamination due to the greater than 24 h time factor for optimum results. Any samples received after 48 h were retaken.

Appendix B.4 illustrates the Certificate of Microbiological Analysis report format forwarded to the Health Units for distribution to survey participants.

2.2.7 Phenoxy/Neutral Herbicide Analysis

A 1-L glass bottle was used to collect water samples which were cooled (approximately 5 °C) and shipped to Enviro-Test Laboratories in Edmonton, Alberta. The water samples were paired by blending 0.5 L of one sample with 0.5 L of another site sample then analysed as a composite sample to decrease project costs. If herbicides were detected in the composite samples, the individual samples were re-analysed separately. Overall the composite results compared closely with the individual re-extraction results. Some variability in the individual versus composite results is expected with this type of re-analysis. There are several factors that affect this, such as the amount of particulate or sediment found in the original sample, and the variability in the quantitation at low levels. The quantitation using HP 5970 Mass Selective Detector with a 5890A Gas Chromatograph (GC/MSD) has a typical coefficient of variation ranging from 10 to 25%. The instrument was run on a selected ion monitoring mode in which 3 ions are selected for each analyte (Bruns, 1996). The identification of an analyte in a sample must be confirmed for all 3 ions at the expected retention time and ion ratios. The variability of the results increases near the quantitation limit (0.05 ppb) due to an increase in signal to noise ratio which may approach 50%. Tests on stability reveal that there is little degradation of herbicides in water stored at refrigerated conditions (0-4 ° C) (Bruns,

1996).

The eight herbicides (MCPA, 2,4-D, dicamba, bromoxynil, triallate, trifluralin, diclofop-methyl, and fenoxyprop) were chosen based on research by Anderson (1995) and Cotton and Bytrus (1995) who utilized provincial sales figures and chemical persistence data as well as field plot and groundwater monitoring research of Hill et al. (1996), Miller et al. (1992), and Rodvang et al. (1992).

The format of the information returned to participants is given in Appendix B.5.

2.3 Results and Discussion

While a total of 820 farm sites were visited, sampled and surveyed during 1995 and 1996; some discrepancies in the numbers reported were encountered due to incomplete survey questionnaires or missing samples. The total number of sites sampled was roughly the same each year: 407 water wells in 1995 and 413 water wells in 1996. Of these sites, 816 were completely matched to both the questionnaires and laboratory analysis. A sample questionnaire with results is provided in Appendix B.1 along with copies of the reported analysis (Appendix B.2 through B.5).

Thirty-two percent of the sampled water well sites exceeded the GCDWQ (Health Canada, 1996) maximum acceptable concentration (MAC) or interim maximum acceptable concentration (IMAC) for one or more of the parameters analysed. Approximately 92% of the sites failed to meet the aesthetic objectives (AO) set out under the GCDWQ . Although the samples were randomly collected over a two-year period, little temporal difference in water quality was noted between years.

Statistical analyses (including descriptive statistics, Pearson correlation analysis, and linear

regression analysis) for the FWQS data were performed using SPSS Base 8.0 (SPSS, 1998) statistical software.

2.3.1 Herbicides

In the 1994 pilot project no herbicides where detected in the 73 well water samples analysed. However, 27 (3.3%) of the 820 samples from the FWQS had measurable herbicide detections of 0.05 μg/L or greater except for fenoxaprop at a detection level of 0.10 μg/L or greater. Of those sites with a detection (Figure 2.4), 29.6% had more than one herbicide present. The GCDWQ lists MAC or IMAC levels for six of the eight herbicides analysed, which along with detection numbers and concentrations found at the sites are tabulated in Table 2.1.

Four samples contained levels of bromoxynil, two at less than 1 μg/L and one at a concentration of 29 μg/L, which exceeds the IMAC guideline of 5 μg/L. Five samples had measurable amounts of dicamba. While none exceeded the guideline of 120 μg/L, the largest concentration detected was 9.50 μg/L. Two of the twelve samples containing measurable amounts of 2,4-D exceeded the guidelines (100 μg/L), with the highest concentration being 206 μg/L. However, eight samples contained less than 1 μg/L of 2,4-D. Two samples contained detectable levels of diclofop-methyl;one sample had 0.094 μg/L, and the other had a concentration of 3 μg/L. The CDWQG for diclofop-methyl is 9 μg/L. Fenoxaprop at a concentration of 3.40 μg/L was found in one sample. However, there is no guideline for fenoxaprop under the current GCDWQ; therefore, it is not known at what level human health may be compromised. One sample had a detectable concentration of 0.80 μg/L of trifluralin. Seventeen of the samples contained measurable amounts of MCPA; the highest concentration was 3.10 μg/L. Currently, MCPA is under review (Caux et al., 1995; Health Canada, 1996) with a possible guideline of 10 μg/L which is in keeping with the United States Environmental Protection Agency. Finally, one site had a detected triallate (MAC = 230 μg/L) concentration of 3.10 μg/L.

Contamination of water wells by herbicides is often linked to site specific practices (herbicide handling) and is generally not indicative of widespread contamination. Kross et al. (1992) found that 25% of the wells that had pesticide levels which exceeded the Lifetime Health Advisory Levels in Iowa were due to point source contamination from back-siphoning or spills. It was noted by FWQS sample team members that at two of the 27 sites, back-siphoning of herbicides into the well had occurred. Frank (1981) noted that in a ten-year period between 1969-1978 in Ontario, 19% of 159 contaminated wells were contaminated due to accidental back-siphoning, overfilling, or rinsing spray equipment, while 31% of the pesticide contamination cases were caused by spraying weeds or crops close to the well. Survey data for the FWQS indicated that only 37% (10 / 27) of the sites with a detection made use of the water well as a spray water source. This relationship to the non-spray water use detections was not pursued any further under the FWQS. At only one of the 27 sites did the respondents indicate that general herbicide application activities had occurred within 50 m of the wellhead.

Well owners were asked through the use of the survey questionnaire if herbicides applied on fields (47 / 820 responded yes) or herbicide tank mixing / washing operations (150 / 820 responded yes) were a potential source of contamination to their water supply. Of those who responded yes to the above question, nine had a herbicide detection. Respondents at 8 of the 27 locations with a detection believed field applied herbicides had more of a contaminant potential then 2 of 27 for tank mixing which could be directly related to management practice at the wellhead.

2.3.2 Nitrates

Historically, concern about nitrate levels has been due to cases of cyanosis or methemoglobinemia (blue baby syndrome) in infants. More recently, nitrate levels at higher concentrations have been associated with increased rates of non-Hodgkins lymphoma (Weisenburger, 1990). Although nitrate (NO_3^-) is the main form in which nitrogen occurs

in groundwater, dissolved nitrogen also occurs in the form of ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2), nitrous oxide (N_2O), and organic nitrogen (Freeze and Cherry, 1979). For the purpose of the FWQS data all nitrate values are reported as nitrate+nitrite concentrations. Water is considered unsafe to drink if the nitrate+nitrite concentration exceeds the MAC of 10 mg/L.

Nitrate contamination is often associated with nitrogen fertilizers, barnyard manure, and septic systems used on farms and by rural residents. However, some aquifers in Alberta contain water with nitrate concentrations as high as 1800 mg/L (Hendry et al., 1984; Pupp et al., 1989). Madison and Bruett (1985) found that in a U.S. water quality survey, nitrate levels greater than 3 mg/L were generally of anthropogenic nature. The mean nitrate concentration from the FWQS samples was 2.19 mg/L (standard error of mean ± 0.27 mg/L) which would lend support to the assumption made by Madison and Brunett (1985), that levels above a 3.0 mg/L might be suspect to anthropogenic sources. However, 60% of the samples were at or below the limit of quantitation (LOQ) (0.05 mg/L). Six percent of the samples (46) tested had concentrations of nitrate that exceeded the MAC of 10 mg/L. These 46 nitrate detections were randomly distributed throughout the province (Figure 2.5). The number of samples exceeding the MAC for nitrate (NO_3^-) in these Alberta data appears to be lower than values reported in Ontario (14%) by Gross et al. (1997), in Nebraska (19%) by Gosselin et al. (1997), and Missouri (22% > 45 ppm NO_3^-) by Sievers and Fulhage (1992); however, similar to those values found in Montana (6%) by Bauder et al. (1991).

Four hundred and eighty six of the 816 FWQS sites (60%) had concentrations below the limit of detection (0.05 mg/L). A higher mean concentration was observed in 1996 (2.53± 0.35 mg/L) versus 1995 (1.88±0.43 mg/L). However, there was no significant correlation between the year the sample was taken and NO_3^- concentration ($p=0.241$). This slight difference may be due in part to a greater number of dug wells in 1996 (89 in 1996 versus 78 in 1995) and a greater number of shallow wells (<30 m) sampled in 1996 (167 / 409 with a mean depth = 44 m) versus 1995 (155 / 407 with a mean depth = 47 m). Baker et al.

(1990), Dasika and Atwater (1995), and Kross et al. (1993) found that sites with high levels of nitrates appeared to be most prevalent in shallow wells within unconfined aquifers. Forty four of the 46 FWQS samples exceeding the 10 mg/L nitrate MAC were from water wells less than 30 m deep. This observation was also made by Rudolph and Goss (1993) in the Ontario Farm Groundwater Quality Survey, where depth of well along with well age and construction type were significantly correlated with nitrate concentrations.

Determining the physical condition of the well, including casing, seal, or pit would provide additional confirmation of possible entry of nitrates from a surface or near-surface source rather than the groundwater supply. Exner and Spalding (1985), Sievers and Fulhage (1992), Sharpe et al. (1993) and Goss and Barry (1995) provided this rationale for the large percentage of elevated nitrate detections. Exner and Spalding (1985) also concluded that wide ranges in nitrate concentration and a high degree of aquifer heterogeneity over a short areal distance is indicative of point source contamination. Similar results are likely for Alberta given similar aquifer conditions. However, Hallberg (1987), in an Iowa study, found that nitrate contamination in less than 2% of the wells sampled could be attributed to well placement or construction problems.

The use of commercial fertilizers within 50 m of the FWQS wells where NO_3^- exceeded the 10 mg/L MAC was 8.7% (4 / 46) in comparison to 8.4% (65 / 770) of the sites where the MAC for NO_3^- was not exceeded. Hallberg (1987) stated that groundwater contamination may not be evident for many years after excess fertilizer-N use begins in areas with a thick, medium to fine textured soil mantle, and that aquifers which are more deeply buried may simply not have had enough time for the surficial applied chemicals of the past 10 to 20 years to reach these deeper portions of the Iowa groundwater system.

Other factors which can influence the NO_3^- concentration in groundwater, as previously indicated, include septic systems and livestock and their associated manure. Seventy-eight percent (36) of the 46 sites exceeding the MAC for NO_3^- had livestock while 75% (576 / 770)

of the FWQS sites that did not exceed the MAC for nitrate also had livestock. As well, septic systems within 50 m of the well were considered a potential for NO_3^- contamination. The FWQS data indicated 33% (16 / 46) of the NO_3^- contaminated sites had a septic system within 50 m of the well as compared to 21.6% (159 / 770) of the sites with nitrate less than the MAC had a septic system within this distance. For the overall results of the FWQS septic systems within 50 m of the wellhead were not found to be significantly related to NO_3^- concentrations ($p = 0.098$ and $r^2 = 0.003$).

2.3.3 Coliform

The detection of coliform in water is not necessarily an indication of faecal contamination in the water. However, the presence of faecal coliform, a subgroup of the coliform group, would indicate the presence of faecal contamination. Some species of bacteria in the faecal group will occur naturally in soil and on vegetation, however, species within the group *Escherichia coli* are a definite indicator of the presence of faecal contamination from a warm-blooded source. The GCDWQ MAC for drinking water is zero faecal coliform detected per 100 mL. If they are present, the water source should not be used until it is detection free.

Some of the obvious sources of faecal contamination include near surface entry into the well from septic systems, manure storage facilities, farmyard faecal sources, vermin gaining entry into the well, livestock and pets living too close to the well head or the presence of a compromised well seal. Rudolph et al. (1992) found 31% of the 1300 wells sampled in Ontario exceeded total coliform levels and 20% exceeded the faecal coliform levels. Detected concentrations in Ontario were not significantly correlated to presence of animals, proximity of septic system, or manure storage.

In Alberta, in the FWQS study, 3.1% (25 / 816) of the sites tested positive for faecal coliform (Figure 2.6), while 7.6% (62 / 816) of the samples exceeded the MAC (> 10 colonies per 100 mL) for total coliform and 13.8% (113 / 816) of the samples tested positive for total coliform

greater than 1 colony per 100 mL (Figure 2.7). Coliform bacteria were detected in 20.1% (66 / 329) of the wells with a depth less than 30 m of which 53 were dug wells. In comparison, 9.6% (47 / 487) of the wells with a depth greater than 30 m tested positive for the presence of coliform bacteria.

Presence of livestock did not significantly contribute to the presence of total coliform bacteria ($p = 0.930$) as 11.9% (73 / 612) of the sites with livestock had total coliform detections as opposed to 19.6% (40 / 204) of those sites without livestock having total coliform detections. Other factors which may affect the presence of bacteria at the well include the presence of old unused wells ($p = 0.313$), use of well pits ($p = 0.597$), and pooling of surface water ($p = 0.313$) at the well head. The comparison between the factors such as proximity of the well to corrals, feedlots, manure storage, manure application, and septic systems can potentially increase bacteria levels in wells; however, this relationship was not statistically significant from the FWQS data (Table 2.2).

The mean age of wells containing total coliform was 20.4 ± 1.6 y and without total coliform 19.5 ± 0.58 y. The mean age of the septic system at sites with total coliform was 17.7 ± 1.3 y and those without total coliform was 17.3 ± 0.4 y. While many of the sites made use of some form of treatment, few had water disinfected before it was used. Approximately 49 % of the sites that had a total coliform detection had either no previous testing (15 / 112) or had only initial testing (40 / 112) when the well was first completed.

Hallberg (1987) noted that in a review of over 16,000 water quality analyses from northeastern Iowa, bacterial problems were randomly distributed in relation to geologic setting and well depth. This observation was also made for the FWQS data from Alberta (Figure 2.7).

2.3.4 Chemical and Trace Metal Analyses

Twenty-five percent (206 / 816) of the FWQS well water samples exceeded either the MAC or IMAC GCDWQ for one or more of the following elements: arsenic, barium, chromium, fluoride, lead, nitrate, selenium, and uranium. In addition, 92% (754 / 816) of the sites exceeded the aesthetic objectives (AO) set for chloride, copper, iron, manganese, pH, sodium, sulphate, total dissolved solids, and zinc. Summaries for both the chemical and trace metal analyse are provided in Table 2.3 and Table 2.4, respectively; the data were not significantly different between years. Most of the trace metal samples had non-quantifiable levels of antimony, beryllium, cadmium, cobalt, silver, thallium, and vanadium.

2.3.5 Parameters Exceeding the MAC or IMAC

Thirty-one percent of the samples had concentrations of fluoride that were low enough (less than 0.5 mg/L) that the daily intake of fluoride would require supplementation to ensure adequate intake for proper bone and tooth development. Approximately 13% of the samples had levels that exceeded the MAC of 1.5 mg/L; 71 samples had concentrations between 1.5 and 2.5 mg/L, 22 had concentrations between 2.5 and 3.5 mg/L, and 3 samples had concentrations between 3.5 and 4.0 mg/L. Nine samples had concentrations that exceeded 4 mg/L and one sample contained 6.4 mg/L fluoride (Figure 2.8).

The IMAC for arsenic is 25 μg/L. Only 2.5% of the sample sites tested had concentrations that exceeded the IMAC levels; 49.6% (406) of the samples tested had levels of arsenic below the 1 μg/L limit of quantitation (LOQ). In addition, 47% (386) of the samples had concentrations that were measurable but below the IMAC level (Figure 2.9). Of the 21 samples (2.5%) that had concentrations of arsenic that exceeded the IMAC level, two samples had concentrations greater than 100 μg/L.

Miller et al. (1996) encountered concentrations of arsenic as high as 5340 μg/L in southern Alberta in shallow (2.18 to 10.8 m) saline well sites which were hillside seep or artesian discharge in nature. Welch et al. (1988) found aquifers underlain by sandstone or carbonate

rocks were low in arsenic; however, higher concentrations in the Western United States were associated with basin-fill deposits of alluvial-lacustrine origin, mainly in semi-arid areas or in volcanic deposits or under the effects of geothermal systems or in uranium and gold mining areas. Arsenic can be derived from arseno-sulfide minerals, phosphate rock, fertilizers, or pesticides (Miller et al., 1996; Welch et al., 1988). As well, the mobility of arsenic in sedimentary aquifers may be, in part, a result of changes in the geochemical environment due to agricultural irrigation. At greater depths, high concentrations are associated with compaction caused by groundwater withdrawals (Welch et al., 1988). It is, therefore, concluded from the FWQS data that generally the elevated arsenic levels are the result of natural aquifer conditions; however, without further investigation anthropogenic factors cannot be eliminated.

One percent of the FWQS samples obtained in each of the two years exceeded the MAC of 1000 μg/L for barium.

Only 2 samples (0.2%) had levels of chromium that exceeded the MAC of 50 μg/L. Levels near or greater than the IMAC are usually attributed to plumbing fixtures or other anthropogenic sources.

The majority of the samples had very low concentrations of lead (mean = 1 μg/L with 628 < LOQ). Most samples had less than the MAC of 10 μg/L. Thirteen samples had concentrations between 10 μg/L and 100 μg/L and one sample had a concentration of 137 μg/L. Lead poisoning has been associated with lead pipes used for plumbing in older houses (Swistock et al., 1993). However, the sample containing 137 μg/L was from a new modular home with a well less than 3 months old. On re-sample (four weeks later) the levels were well below the MAC.

Three percent, 28 samples, were found to have levels of selenium (Se) that exceeded the MAC of 10 μg/L (Figure 2.10). Of these 28 samples, the majority (23 samples) had

concentrations below 30 μg/L; two samples had concentrations between 41 and 50 μg/L, and 3 had concentrations greater than 50 μg/L. Steichen et al. (1988) found 9 / 103 Kansas well sites with Se levels above 10 μg/L, attributing some of these concentrations to naturally occurring soil and rock formations in exposed cretaceous shales. Miller (1978) found that 30% of the 160 wells tested in a Montana study had Se levels which exceeded the MAC. In Alberta, Warren and Dudas (1992) found Se concentrations generally less than 0.5 mg/kg in till materials; however, weathering of shallow outcrops of sedimentary rocks such as shales with pyrite may induce higher Se levels in parts of Alberta (Miller et al., 1996). Other possible selenium sources include fertilizers and feed additives (Miller et al., 1996).

Less than one percent (3 / 816) of the sample sites had concentrations of uranium that exceeded the MAC of 100 μg/L. These levels are interpreted as naturally occurring due to the background geology of the aquifers from which the water was drawn. In all three cases, concentrations of TDS, sulfate, sodium, and selenium, or nitrate were above the GCDWQ; as well, two of the sites had concentrations of chloride, and boron or manganese above the MAC or AO guidelines. At only one of the sites was the water consumed by the residents. At that site health related problems were noted; however, these problems were attributed to sodium levels. The other two sites made use of the water supply for livestock and health problems in the stock were also noted.

2.3.6 Parameters Exceeding the Aesthetic Objectives

Ninety-two percent of the 816 FWQS well water samples exceeded the aesthetic objectives (AO) defined by the GCDWQ. While the AO many not have a direct health effect, exceeding the AO may decrease the palatability of drinking water, increase staining of fixtures and laundry, or interfere with water treatment processes (Health Canada, 1996). It is only when the concentration of a single contaminant exceeds the AO by some subjective amount might there be an assumed health implication.

Fifty-two samples (6.4%) had concentrations that exceeded the AO of 250 mg/L for chloride. The water supply was treated at 21 of the 52 sites; however, at only 11 sites were treatment methods used that were capable of removing chloride ions. Nine samples contained more than 1000 mg/L of chloride and one sample contained 3150 mg/L.

The AO for pH defined by the GCDWQ lies between 6.5 and 8.5. Twenty-three percent (186 / 816) of the samples exceeded these guidelines.

Almost two-thirds (523 / 816) of the FWQS samples had sodium concentrations that exceeded the GCDWQ AO of 200 mg/L (Figure 2.11). At this level of sodium the taste of the water can become offensive. Twenty-three samples had concentrations of sodium that exceeded 1000 mg/L with one sample having 2100 mg/L. Thirteen percent (67 / 523) of those respondents whose water exceeded the GCDWQ for sodium also indicated that they used a water softener. Approximately 67% (45) of those sites with high sodium and softening equipment also had a total hardness greater than 200 mg/L, with the highest being 2324 mg/L. Treating the water to make it softer by replacing the calcium and magnesium ions (to reduce total hardness) with sodium only increases the sodium content of the water that in these cases already exceed the AO, thus increasing potential health concerns.

Seventeen percent of the samples taken in 1995 and 19% of the samples taken in 1996 exceeded the AO of 500 mg/L for sulfate set in the GCDWQ. Fifty water samples had concentrations of sulphate greater than 1000 mg/L, with one sample containing 3370 mg/L.

Eighty-five percent (697) of the samples taken exceeded the AO guideline of 500 mg/L for total dissolved solids (TDS) (Figure 2.12).

A large proportion of the samples had high concentrations of iron. Thirty-six percent (296 / 816) of the samples had concentrations that exceeded the AO of 0.3 mg/L for iron (Figure 2.13). None of the samples had concentrations that were high enough to cause health

concerns. The majority (76%) of respondents whose well water samples indicated high levels of iron claimed to have staining problems due to the water and 31% of those made use of an iron filter to remove some of the iron from their water. Approximately 44% of those with high iron concentrations indicated that they shock chlorinated their well or used chlorine for bacteria-related problems.

Thirty-four percent (281 / 816 samples) had measurable levels of manganese that exceeded the AO concentration of 50 μg/L (Figure 2.14). Approximately 2 / 3 of these sites (178) with a manganese concentration greater than 50 μg/L also had a iron concentration greater than 0.3 mg/L.

Eleven (1.3%) of the samples had levels of zinc that exceeded the aesthetic objectives of 5000 μg/L. The greatest concentration measured was 17,606 μg/L. The majority of these sites (9 /11) with high zinc concentrations represent large diameter wells less than 30 m deep. These wells likely had galvanized well cribbing although this was not investigated further.

Although the GCDWQ do not currently include criteria for aluminum, a level of 200 μg/L has been proposed (Health Canada, 1996). The exposure level established for occupational safety is 200,000 μg/L. Ninety-seven percent (800 samples) had levels of aluminum lower than the proposed limit of 200 μg/L. Ten of the samples tested had concentrations between 200 and 700 μg/L, and 3 samples had concentrations that exceeded 700 μg/L.

Eighty-one percent of the participants indicated that they had tested their water at some time; however, 59% of all the participants had not tested their water in the last five years or tested at all. A total of 40% of the respondents to the Farmstead Water Quality Survey indicated that they made use of some form of water treatment, primarily water softeners (22%), water distillers (13%), iron filters (12%), reverse osmosis systems (3%) or some form of disinfection (3%). The level of treatment and testing is of concern, especially, in those cases where concentrations of any given parameter have the potential to cause health risks.

2.4 Conclusions

Of 820 farm water wells surveyed, 32% exceeded the GCDWQ for MAC or IMAC of at least one parameter (including herbicide and coliform detections exceeding the MAC or IMAC). In addition, 92% of the sites exceeded the GCDWQ for at least one of the aesthetic objectives (AO). Some of the higher parameter concentrations detected in the water samples tested (i.e. herbicides, coliform, nitrates, lead, zinc, chromium, and aluminum) can likely be attributed to anthropogenic influences from agricultural activities or through the household water distribution system. The majority of analyses with higher concentrations of most parameters (i.e. aluminum, arsenic, fluoride, iron, sodium, etc.) are due to natural geological conditions which are defined by the mineralogy of the source aquifers. While the evaluation of the FWQS data helps to identify some site-specific as well as some province-wide problems primarily related to natural geological conditions of the source aquifers, the effects of primary agriculture are likely limited to the 3% herbicide detections and to some nitrate and microbiological contaminations observed.

Some of the 27 sites with detectable herbicide concentrations were likely the result of improper handling of herbicides at the wellhead. However, at 63% (17 / 27) of these sites the respondents indicated that the water source tested had not been used for herbicide spray water, and therefore, no herbicides were mixed at the wellhead or farmyard. The average depth, age, and activities occurring around the wells with herbicide detections were consistent with the characteristics of those wells where detection did not occur.

The FWQS was a one time survey to establish benchmark conditions; therefore, it did not allot resources to measure movement of the herbicides detected within the specific aquifer. These measurements may have identified other sources or farm operations which could be a contaminant source through the local groundwater recharge process. As well, with survey data such as the FWQS data there is a degree of uncertainty whether the survey respondents answered all questions truthfully, with full knowledge of the activities of the farm or fully

understood the nature of the question being asked of them.

The number of herbicide detections were similar or lower than those in other areas of North America. Of the 27 sites all but one had no detection or a significant decrease in the herbicide levels when the sites were re-sampled. This observation is in keeping with the findings of others that seasonal fluctuations based on local agronomic practices have the potential to affect groundwater quality as do the direct timing and handling of the herbicides. This temporal effect related to agronomic practice needs to be addressed through sample protocol in order to better identify cause and effect relationships which the FWQS data can not.

The nitrate results from these data were similar to those of Gross (1997), Pupp et al. (1989), Henry and Meneley (1993) as well as others. The influence of livestock and their associated corrals and feedlot areas as well as the spreading and storage of manure or proximity of septic systems to the wellhead did not significantly affect nitrate concentrations observed, a trend similar to that of Goss (1997) and Hallberg (1987).

There was no significant correlation between bacteria detections (14% of the 816 sites sampled) and either nitrate levels or presence of livestock, manure, or septic systems. The shallower wells (<30 m) sampled were not significantly related to total coliform detection ($p = 0.500$) as was the case for older wells and total coliform detection ($p = 0.596$).

Fluoride, selenium, boron, uranium, lead, chromium, and arsenic were found at levels above the GCDWQ MAC. While most of these exceeding levels would be natural due to the background geological conditions of Alberta (Pupp et al., 1989 and Miller et al., 1996), presence of lead and some of the other parameters would likely be due to the water distribution system (i.e. well casing, waterlines, connections, and faucets).

The GCDWQ MAC is set at a low enough level to avoid health risks even if the water

contains that substance at that concentration, and is consumed for an entire lifespan. However, some chemicals for which a MAC is defined are more toxic than others, or may affect individuals differently, depending upon the health and age of the individual. Therefore, the suitability of the water at 32% of the sites that exceeded the MAC and IMAC for at least one component is considered poor and should not be used for human consumption without some form of treatment, designed specifically for that site.

The suitability of on-farm water supplies based on the single FWQS sampling of the 820 water wells from across Alberta indicated a high percentage (92%) that exceeded the GCDWQ for one or more AO. The majority of those objectives included: total dissolved solids (85%), sodium (64%), iron (36%), and sulfate (19%) at levels higher than the GCDWQ. These parameters clearly reflect the aquifer geology from which the water was drawn. However, it should be noted that the guidelines provide a standard that is low enough so occasional exposure to water above the standard, or exposure to amounts that are only slightly above the standard, will not result in an adverse health reaction.

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Table 2.1 Guidelines and descriptive statistics for selected herbicides analysed (data from 816 Farmstead Water Quality Survey sites surveyed 1995-1996).

Name of Herbicide	GCDWQ MAC (μg/L)	GCDWQ IMAC (μg/L)	Number of Detections	Maximum Detection (μg/L)	Detection Limit (μg/L)
Dicamba	120		5	9.50	0.05
MCPA		10**	16	3.10	0.05
2,4 - D	100		12	206.00	0.05
Bromoxynil	5		4	29.00	0.05
Fenoxaprop*			1	3.40	0.10
Diclofop-methyl	9		2	3.00	0.05
Trifluralin		45	1	0.80	0.05
Triallate	230		1	3.10	0.05
* no standard set in GCDWQ			** under review		

GCDWQ - Guidelines for Canadian Drinking Water Quality
MAC - Maximum Acceptable Concentration
IMAC - Interim Maximum Acceptable Concentration

Table 2.2 **Farmyard practices that can potentially affect total coliform (TC) bacteria detection levels (data from 816 Farmstead Water Quality Survey sites surveyed 1995-1996).**

Practices	Number of wells with TC (113)	Percent of total sites with TC	Number of wells without TC (703)	Percent of total sites without TC
Unused wells	44	39	313	45
Water pooling at well	9	8	39	6
Well pit used	38	34	219	31
Septic System < 50 m from well	25	22	151	21
Livestock present	73	65	614	87
Livestock at Code Levels*	9	8	74	11
Corral < 50 m from well	23	20	200	28
Feedlot < 50 m from well	9	8	58	8
Manure storage < 50 m from well	4	3.5	31	4
Manure applied < 50 m from well	1	0.8	39	6
* 1995 Code of Practice for the Safe and Economical Handling of Animal Manure				

Table 2.3 Descriptive statistics for analyses of chemical properties (data from 816 Farmstead Water Quality Survey sites surveyed 1995-1996).

	Statistical Data							CDWQG (1996)			
Parameter	Units	Mean	Std. Error	Median	Minimum	Maximum	LOQ	No. < LOQ	Standard	No. > MAC	No. > IMAC	No. > AO
Alkalinity Total	mg/L	549.0	7.8	525.0	3.9	1490.0	1.00					
Bicarbonate	mg/L	658.6	9.3	621.5	44.0	1816.0	1.00					
Calcium	mg/L	93.1	2.7	33.0	<1	606.0	1.00	2				
Carbonate	mg/L	5.3	0.4	0.0	0.0	178.0	0.00					
Chloride	mg/L	65.8	7.3	9.8	0.0	3150.0	0.50	4	250.0			51
Conductivity	uS/cm	1639.8	35.3	1370.0	234.0	8930.0	10.00					
Fluoride	mg/L	0.7	0.0	0.4	0.0	6.4	0.05	2	1.5	105		
Hardness	mg/L	261.5	11.7	128.5	1.0	2324.0	1.00	2				
Iron	mg/L	0.8	0.1	0.1	0.0	31.4	0.02	65	0.3			293
Magnesium	mg/L	25.4	1.3	10.0	0.0	385.0	1.00	144				
Nitrate+Nitrite (N)	mg/L	2.2	0.3	0.1	0.0	116.0	0.05	486	10.0	46		
pH		8.1	0.0	8.1	6.4	9.2			6.5-8.5			188
Potassium	mg/L	4.1	0.2	2.8	0.4	122.0	0.20					
Sodium	mg/L	323.6	9.5	301.0	4.0	2100.0	1.00		200.0			523
Sulphate	mg/L	284.3	13.8	111.5	0.0	3370.0	2.00	85	500.0			157
Total Dissolved Solids	mg/L	1107.0	25.1	905.0	134.0	5652.0	1.00		500.0			692
	LOQ = Limit of Quantitation as defined by the IUPAC Convention (Analytical Chem. June 1983) (Adapted from: Fitzgerald et al., 1997) ** Under Review								MAC = Maximum Acceptable Concentration IMAC = Interim Maximum Acceptable Concentration AO = Aesthetic Objective CDWQG -Canadian Drinking Water Quality Guideline			

Table 2.4 Descriptive statistics for analyses of trace elements (data from 816 Farmstead Water Quality Survey sites surveyed 1995-1996).

		Statistical Data							GCDWQ (1996)			
Parameter	Units	Mean	Std. Error	Median	Minimum	Maximum	LOQ	No. < LOQ	Standard	No. > MAC	No. > IMAC	No. > AO	No. Exceeding
Aluminum	µg/L	13.3	2.0	3.0	<1	779.0	1.00	277	**200.00				13
Antimony	µg/L	2.0	1.7	0.0	<1	1414.0	1.00	713					
Arsenic	µg/L	3.5	0.3	0.5	<1	119.0	1.00	406	25.00			21	
Barium	µg/L	100.3	7.0	45.0	<1	2751.0	1.00	1	1000.00	7			
Beryllium	µg/L	0.3	0.2	0.0	<1	192.0	1.00	811					
Boron	µg/L	431.3	17.9	264.0	<1	4346.0	1.00		5000.00				
Cadmium	µg/L	0.0	0.0	0.0	<1	9.0	1.00	810	5.00				
Chromium	µg/L	8.8	0.2	7.0	<1	71.0	1.00	24	50.00	2			
Cobalt	µg/L	0.1	0.0	0.0	<1	24.0	1.00	769					
Copper	µg/L	15.0	1.2	4.0	<1	416.0	1.00	163	1000.00			1	
Iron	µg/L	892.1	90.1	98.0	<1	31460.0	20.00	289	300.00			282	
Lead	µg/L	1.0	0.2	0.0	<1	137.0	1.00	628	10.00	14			
Manganese	µg/L	136.7	11.9	18.5	<1	5334.0	1.00	43	50.00			281	
Molybdenu	µg/L	3.6	0.5	1.0	<1	309.0	1.00	301					
Nickel	µg/L	1.5	0.3	0.0	<1	237.0	1.00	578					
Selenium	µg/L	1.8	0.2	0.0	<1	94.0	1.00	594	10.00	28			
Silver	µg/L	0.0	0.0	0.0	<1	2.0	1.00	803					
Strontium	µg/L	605.0		383.0	11.0	6446.0	1.00						
Titanium	µg/L	0.0	0.0	0.0	<1	4.0	1.00	452					
Thallium	µg/L	5.2	1.1	0.0	<1	749.0	1.00	805					
Uranium	µg/L	5.0		0.0	<1	585.0	1.00	479	100.00	3			
Vanadium	µg/L	0.1	0.0	0.0	<1	7.0	1.00	758					
Zinc	µg/L	323.7	45.6	31.0	<1	17606.0	1.00	30	5000.00			11	

LOQ = Limit of Quantitation
as defined by the IUPAC Convention (Analytical Chem. June 1983)

(Adapted from: Fitzgerald et al., 1997) ** Under Review

MAC = Maximum Acceptable Concentration
IMAC = Interim Maximum Acceptable Concentration
AO = Aesthetic Objective
CDWQG - Canadian Drinking Water Quality Guidelines

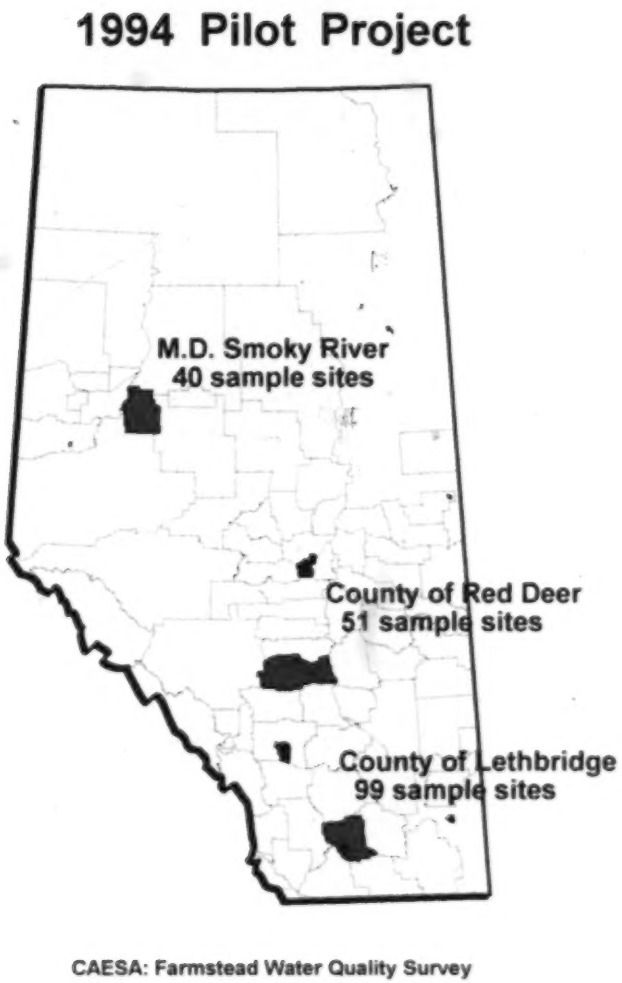

Figure 2.1 Location of Pilot Project Study sample sites by municipality.

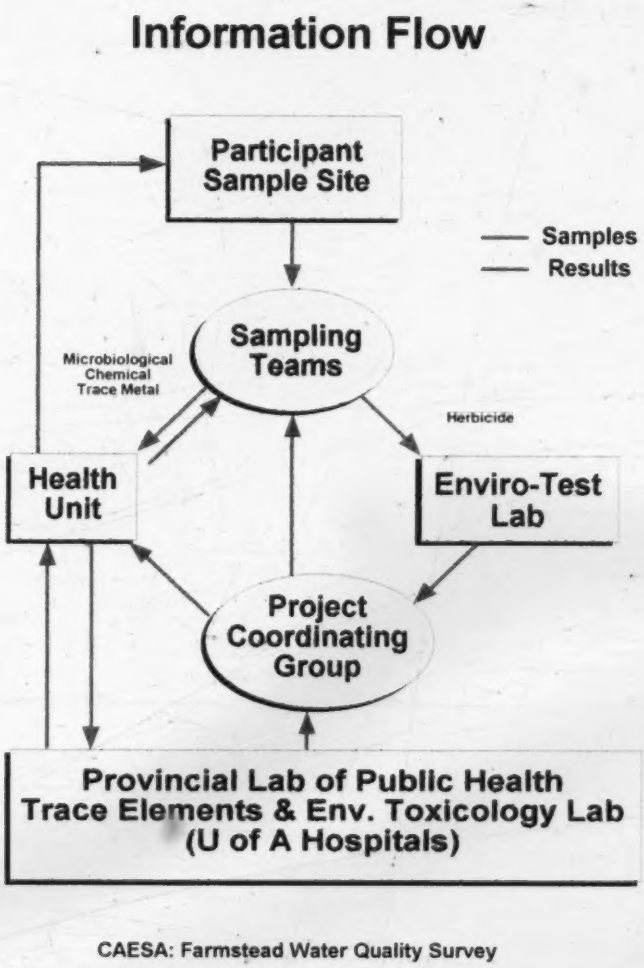

Figure 2.2 Data and sample information flow diagram for Farmstead Water Quality Survey and Pilot Project Study.

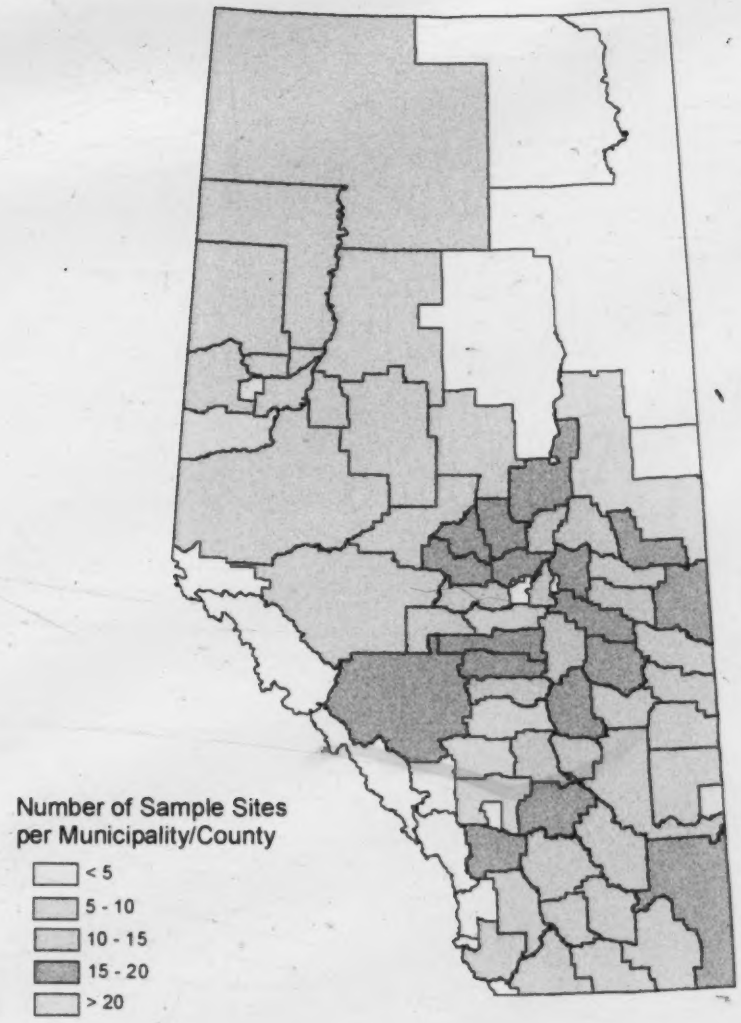

Figure 2.3 Farmstead Water Quality Survey sample sites by municipality.

Figure 2.4 Herbicide detections from 1995-1996 Farmstead Water Quality Survey results.

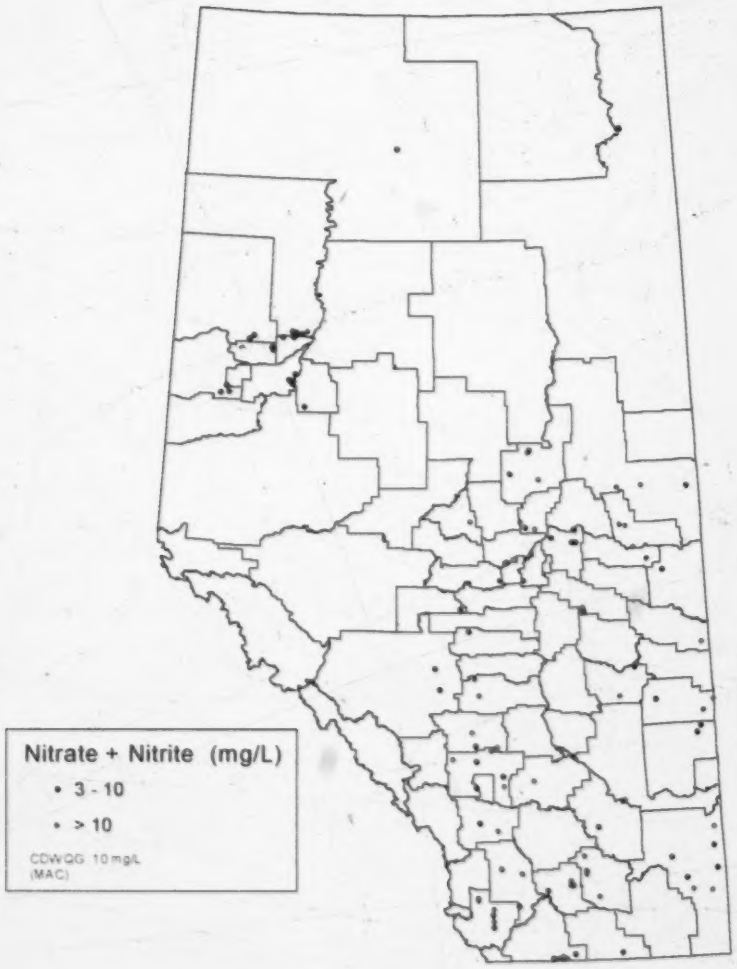

Figure 2.5 Nitrate concentrations >3.0 mg/L from 1995-1996 Farmstead Water Quality Survey results.

Figure 2.6 Faecal coliform detections from 1995-1996 Farmstead Water Quality Survey results.

Figure 2.7 Total coliform detections from 1995-1996 Farmstead Water Quality Survey results.

Figure 2.8 Fluoride detections >1.5 mg/L from 1995-1996 Farmstead Water Quality Survey results.

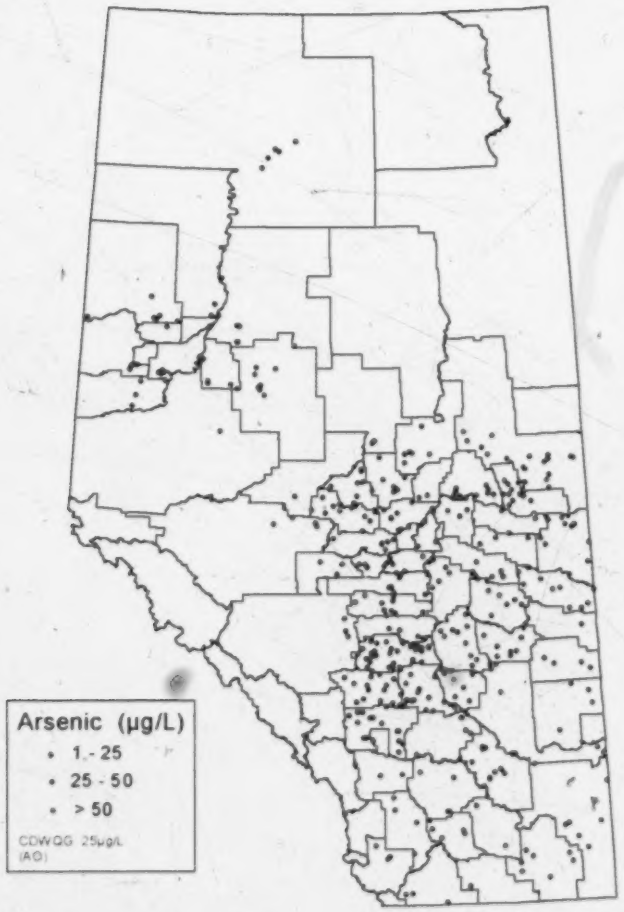

Figure 2.9 Arsenic detections > 1.0 μg/L from 1995-1996 Farmstead Water Quality Survey results.

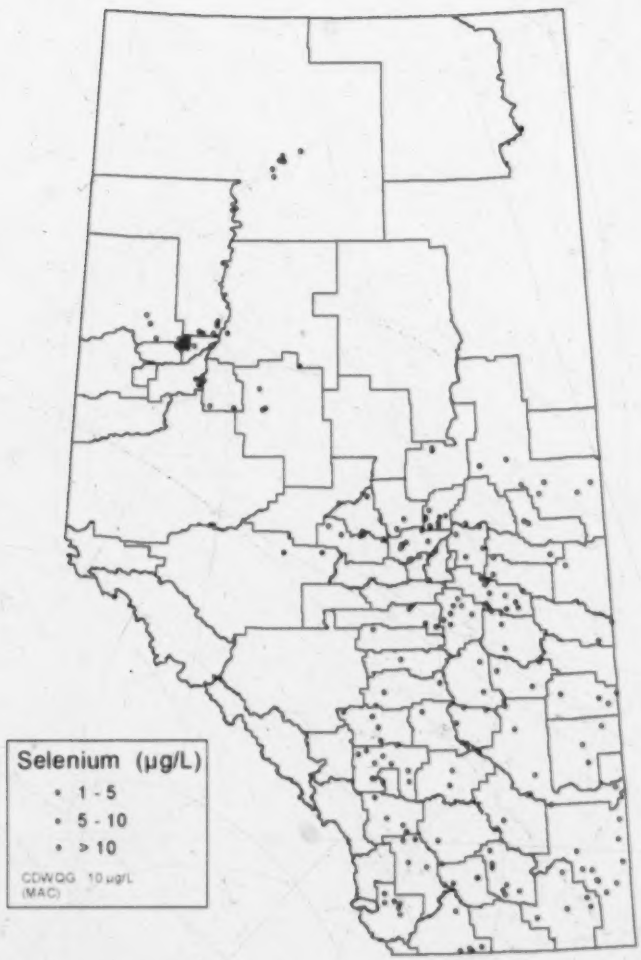

Figure 2.10 Selenium detections > 1.0 μg/L from 1995-1996 Farmstead Water Quality Survey results.

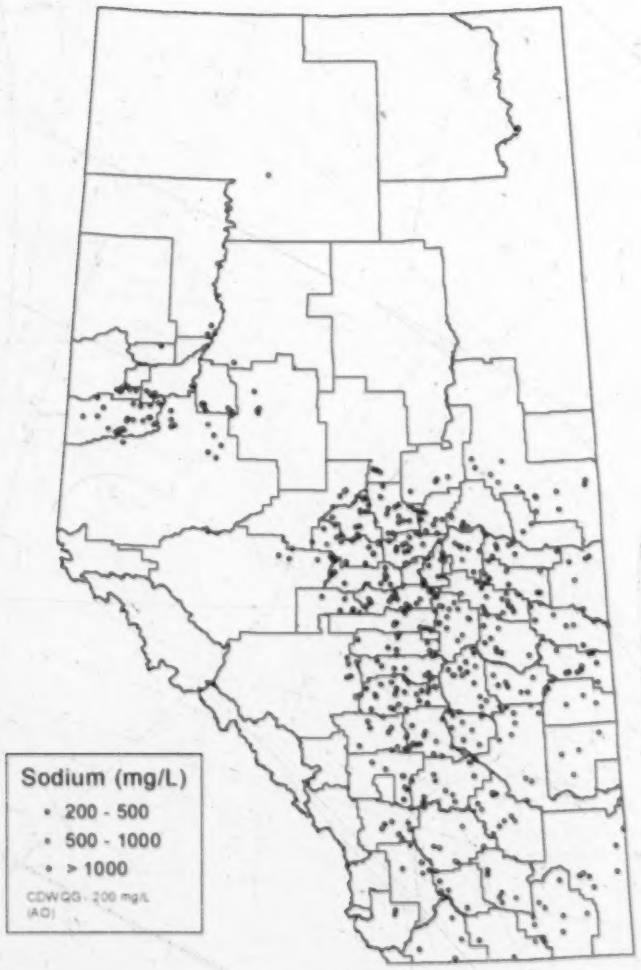

Figure 2.11 Sodium detections > 200 mg/L from 1995-1996 Farmstead Water Quality Survey results.

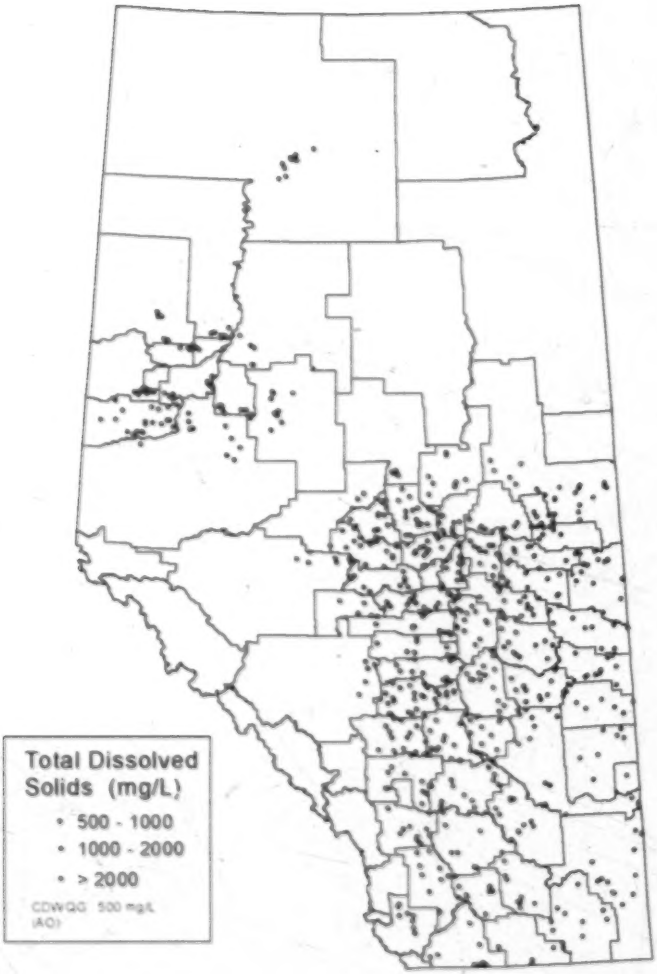

Figure 2.12 Total dissolved solids detections > 500 mg/L from 1995-1996 Farmstead Water Quality Survey results.

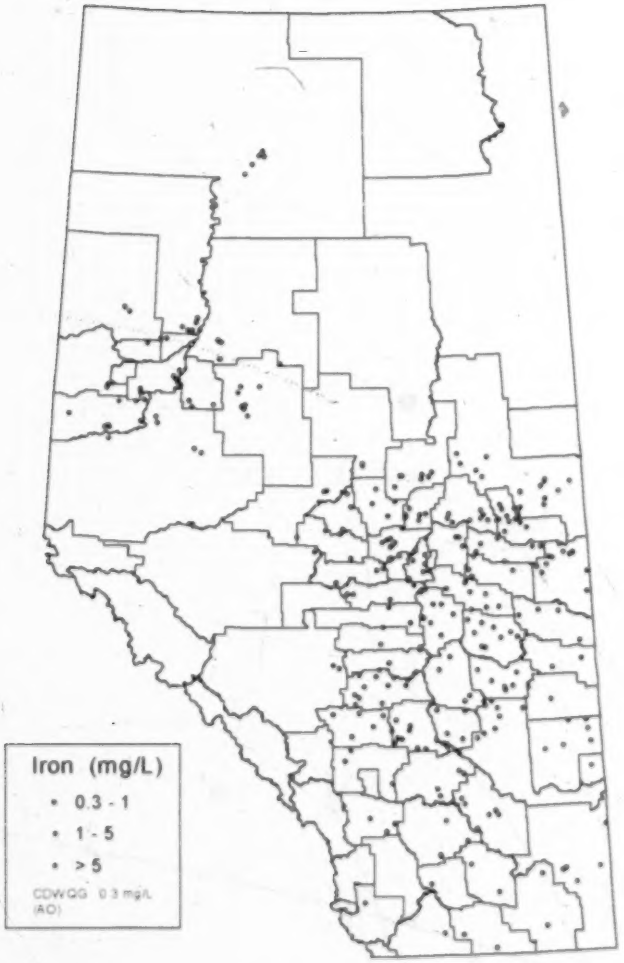

Figure 2.13 Iron detections > 0.3 mg/L from 1995-1996 Farmstead Water Quality Survey results.

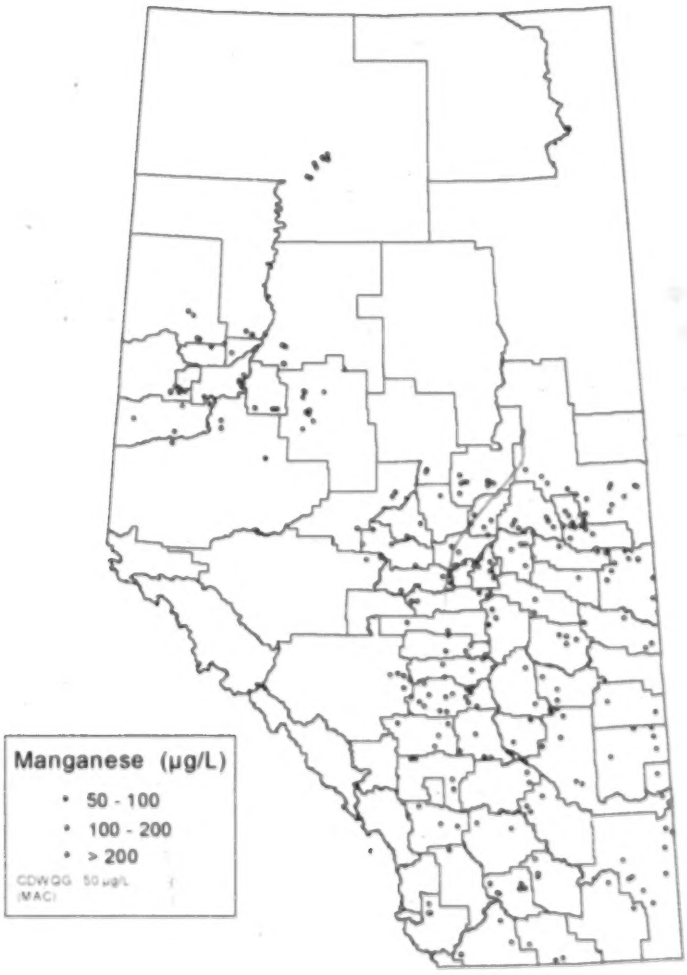

Figure 2.14 Manganese detections > 50 μg/L from 1995-1996 Farmstead Water Quality Survey results.

Chapter 3. Relationship Between Selected Farmstead Water Quality Survey Results And Natural And Anthropogenic Factors

3.1 Introduction to the Relationships Associated with FWQS Results for Nitrate, Total Coliform Bacteria, and Herbicide Levels

In the quest to understand how particular actions cause an outcome, problem is often looked at in the reverse sequence, in that the actions are listed that might be expected to have a significant part in the outcome. An example of this would be to predict the outcome of high nitrate levels in water wells as a function of a combination of the following: natural geology, presence of livestock, presence of a septic system, the design of the well, etc. By comparing these natural and anthropogenic factors with the site-specific water quality results it may be possible to identify linkages between practices and water quality values from a single water sample during a given season.

Gosselin et al. (1997) in Nebraska assessed the overall quality of individual rural domestic water supply systems derived from groundwater. They found that domestic rural water quality varied regionally and was a function of well characteristics, distance to potential contamination sources, and hydrogeologic and site characteristics. While the main focus of the Farmstead Water Quality Survey (FWQS) was to develop a bench mark database of on-farm water well quality in Alberta; this database could be used in the future to evaluate effects of practice changes on water quality or to detect potential environmental or health related problems.

A second objective of the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement's FWQS was to evaluate the impact of primary agriculture on the quality of farm water supplies. Also of importance in the context of water quality in any setting are the effects of the geological conditions as well as factors associated with the construction of the water well from which water is withdrawn. As water samples obtained through the FWQS were collected from drinking water points, at the end of the distribution

system, the samples do not reflect the true conditions of the groundwater. Consequently, the well itself, the pipes and connections, as well as the facet at which the sample was collected may have contributed to the overall chemical composition of the water quality results. Therefore, the natural and anthropogenic characteristics which affect the overall quality of water well supplies need to be examined to identify the impact of agricultural activities. Consequently, the second objective of the project was to determine if the concentration of nitrate or the detection of herbicides and total coliform bacteria in Alberta's groundwater derived on-farm water supplies could be determined by associated water quality parameters, anthropogenic factors, or natural geographic features.

3.2 Natural Water Quality Relationships

Levels of nitrate, total coliform bacteria, and herbicides in farm water wells in Alberta may be directly associated with the concentration of other chemical parameters. Identifying and understanding these associations may be useful for future water quality monitoring or evaluation techniques. Therefore, the SPSS Base 8.0, multiple linear regression procedure, was used to identify the chemical factors (such as major ions, trace elements, and physical characteristics) which contributed to the observed concentrations of nitrate, total coliform bacteria, and herbicides.

3.2.1 Nitrates

Using multiple linear regression, chemical and physical factors associated with the presence of nitrate in the well water samples collected were identified. This relationship, presented in Appendix C.1, provides some understanding of the general influence natural background aquifer chemical composition has on the results observed. The independent chemical variables influencing nitrate concentration ($r^2 = 0.829$ at $p < 0.001$) were limited to the more major ions analysed (Mg^{++} and TDS have a positive relationship to NO_3^- levels, whereas CO_3^-, Fe, K^+, Cl^-, HCO_3^-, Ca^{++}, SO_4^-, total alkalinity, and Na^+ all have a negative relationship).

Whether the relationship presented in Appendix C.1 would accurately identify NO_3^- concentrations at any given site is doubtful. However, 83% of the mean variance in the concentration in the samples was due to 11 chemical parameters while other factors measured in the FWQS were less significant.

The relationship between iron levels and NO_3^- levels was also notable. At iron levels above the observed FWQS mean = 0.84 (± 0.081) mg/L, there is a distinct decrease in the nitrate concentration (Figure 3.1). This decrease would likely be due to denitrification processes which take place in the anaerobic environment under which higher iron concentrations in solution are expected (Croll and Hayes, 1988). This association could allow for the possible pre-screening of water samples for nitrate which may exceed the GCDWQ MAC of 10 mg/L through the use of in-field iron detection methods. This association was also noted by Henry and Meneley (1993). Trudell et al. (1986) found that through denitrification, the loss of nitrates injected directly into the aquifer was associated with declining levels of oxygen and increased levels of bicarbonate in the aquifer studied. This associated relationship between nitrate and bicarbonate concentration was evident in the FWQS data; however, as illustrated in Figure 3.2, this relationship is not as significant as that of iron and nitrate.

Nitrate contamination via septic tanks is often accompanied by high chloride levels (Steichen et al.,1988). The data collected from that Kansas study indicated that 25% of the wells that were high in nitrate were also high in chloride. The relationship between nitrate and chloride levels yielded a low correlation coefficient, $r^2 = 0.0106$, and a non-significant F value at $p = 0.10$ (Steichen et al., 1988). No correlation between nitrate-N and chloride was found for the FWQS samples with nitrate ≤ 10 mg/L ($p = 0.221$) or at nitrate > 10 mg/L ($p = 0.1921$). The mean NO_3^- and chloride concentrations were 0.724 (± 0.064) and 62.39 (± 7.33) mg/L at $NO_3^- \leq 10$ mg/L and 27 (± 3) mg/L and 122.7 (± 39) mg/L, respectively for $NO_3^- > 10$ mg/L. This supports the results of Steichen et al. (1988). The question of relationship or cause is unanswered as a correlation between Cl^- and NO_3^- and the septic system was not significant from the FWQS data.

While 35% of the wells had nitrate concentrations above 10 mg/L, only 3 of 46 had a chloride concentration greater than the AO of 500 mg/L. That this higher Cl^- level can be directly linked to septic system problems based on the septic system's location within 50 m of the wellhead is debatable without further examination of the sites. Other studies (Exner and Spalding, 1985; Murphy, 1992; Rudolph and Goss, 1992) found a significant relationship between distance from the septic system and NO_3^- concentration but the relationship between Cl^- and NO_3^- concentrations was not examined.

A more significant but weak relationship was found between Cl^- levels and well sites within 50 m of the farm fuel storage at NO_3^- concentration > 10 mg/L ($p < 0.001$), but this relationship did not extend to sites where fuel spills near the well were reported on the questionnaire.

3.2.2 Total Coliform Bacteria

There was no correlation ($p = 0.902$) between FWQS sites with high NO_3^- contamination (>10 mg/L) and total coliform (TC) detections, but the mean nitrate concentration was significantly different between sites with TC detections (mean $NO_3^- = 4.223 \pm 0.935$ mg/L) versus sites without TC detections (mean $NO_3^- = 1.879 \pm 0.281$ mg/L). A significant ($p = 0.003$) but weak correlation ($r^2 = 0.011$) exists between nitrate concentrations and TC detections. Kross et al. (1992) also found a significant but weak relationship between NO_3^- and total coliform (TC) detection. As a predictor, they found high nitrate and pesticides a moderately good predictor of TC but TC a poor predictor of NO_3^- and pesticides. This would lead to the assumption that bacterial and NO_3^- contaminations have dissimilar pathways in which they enter the wells. Exner and Spalding (1985) in Iowa concluded that in the absence of a significant correlation between TC and NO_3^- under barnyard conditions, nitrogen in surface layers oxidized and moved downward into the unsaturated zone; thus, the surface layer in time would be low in NO_3^- but high in TC which through direct injection around the

well casing would gain entry to the well.

Furthermore, Exner and Spalding (1985) found wells not located near a potential nitrogen source were least likely to contain TC. This, however, does not support the conclusions of Gosselin et al. (1997) in Nebraska who found that wells contaminated by bacteria generally had low nitrate concentrations.

Chemical factors related to the presence of coliform in the well water samples were non-significant.

3.2.3 Herbicides

Pupp (1989) concluded that "The prairies, with the possible exception of some areas in Manitoba, appear to be less at risk, probably because of the different hydrogeology (largely till), different forms of agriculture (mainly grain), and the low precipitation and high evapotranspiration". While herbicide detection in well water samples is most likely the result of anthropogenic practices, no relationships were found between any of the chemical parameters and observed herbicide detections. Kross et al. (1992) concluded, from their Iowa study, that significant associations between water quality parameters and herbicide detections existed but they were not strong predictors based on state-wide data. In looking for potential predictors that might lead to suspect site contamination, other water quality parameters were not significant based on the provincial-wide FWQS data. Considering the low number of detections (3%) with only 2 out of 820 sites exceeding the MAC, the conclusions made by Pupp (1989) appear to be supported by the FWQS data.

3.3 Agricultural Practices and Well Water Quality

Concern for the impact on water quality due to agricultural practices at the well along with non-point source effects that have been reported elsewhere led to the need for the FWQS to

address the level of impact associated with the agriculture industry in Alberta. Many studies have been conducted in other states and provinces to document the anthropogenic practices, primarily for farming operation, which can contribute large amounts of nitrate, bacteria, and pesticides to the environment. The FWQS set out to identify the impacts of primary agriculture on groundwater quality where possible through a questionnaire (Appendix B.1) matched to the water sample results.

3.3.1 Nitrates

Murphy (1992) concluded, from a New Jersey well water study and the works of others, that "when attempting to predict the vulnerability of a well to nitrate contamination: depth of the well, proximity to a septic tank, and application of fertilizer or manure" were at the forefront. Rudolph and Goss (1993), Sharpe et al. (1993), and Steichen et al. (1988) found that factors correlated to nitrate contamination also included: age of the well, land use around the well, and distance to potential sources of contamination. As the distance to the potential contaminant source is related to land use and the age of the well is often an indicator of the farmstead age, the interrelationship between specific activities over time may be cause for concern.

Steichen et al. (1988) concluded that increased NO_3^- in the spring may be the result of higher moisture levels in soils which coincide with application of most fertilizers and pesticides. Rudolph and Goss (1993) and Hallberg (1987) in Iowa found a significant correlation between the amount of nitrogen fertilizer shipped to a county and the number of wells exceeding the nitrate drinking water limit. The application of commercial fertilizer applied within 50 m of the FWQS wells was insignificant ($p= 0.727$). Comparing commercial fertilizer sales within the specific areas of Alberta to NO_3^- concentration exceeding 3 mg/L did not reveal a significant relationship. Using the data presented by Kryzonowski (1995) on fertilizer purchases (before the FWQS data were collected), the FWQS sites did not correlate to these higher fertilizer-N areas. That fertilizer usage does not

always correlate with high nitrate detection was also noted by Burkart and Kolpin (1993) in a mid-western US study. However, these researchers as well as many others (Bouchard et al., 1992; Freeze and Cherry, 1979; Hallberg, 1987; Madison and Brunett, 1984) concluded that the frequency of nitrate detection is increased with increased commercial-N fertilizer usage under the right conditions. Some of these conditions include soil type, hydraulic conductivity, soil moisture, temperature, vegetation or crop cover, and precipitation in conjunction with NO_3^- use (Madison and Brunett, 1985).

The placement of the well and farming activities in relationship to each other, as well as, the presence of livestock in close proximity to the well can potentially increase the risk of nitrate contamination. The application of manure within 50 m of the FWQS well sites significantly affected the NO^-_3 concentration ($r^2 = 0.005$, $p = 0.043$ with a mean = 4.63 ± 1.31 mg/L). Corrals located within 50 m of the well had a non-significant relationship to NO^-_3 concentration ($p = 0.142$); as well, both storage of manure and feedlot location within 50 m of the well did not significantly affect NO_3^- levels. Rudolph and Goss (1992) also found no significant correlation between nitrate contamination and distance from feedlot or manure storage to the well. Nitrate contamination below active feedlots is likely not significant, primarily due to the compaction and aeration action of the cattle in the feedlot pens (Sweeten et al., 1992); however, as indicated by Madison and Brunett (1985), inactive feedlot soils dry quickly and the processes of nitrification, leaching, and downward percolation into the groundwater can be quick. The rate at which contamination occurs is a function of the amount of nitrate formed, soil hydraulic conductivity, and the amount of denitrification that takes place (Madison and Brunett, 1985).

While the FWQS did not gather data related to manure storage type, much interest is currently being placed on the effects that liquid manure storage facilities have on groundwater contamination in the wake of recent prairie wide expansion efforts in the livestock industry (MacMillan, 1998). Korom and Jeppson (1994) and Ritter and Chirnside (1987) found that seepage from clay lined liquid animal-waste lagoons presented a threat to

local groundwater when the storage was completely drained as shrinking and cracking of the clay liner allowed seepage of wastes until the clays swelled and sealed the cracks. This process created a wide variation in NO_3^- concentrations in observations wells in close proximity to the lagoon during draining and refilling of the lagoon. While dairy, poultry, and hog operations often use liquid storage systems, it is more typical of piggeries and dairies. Some inferences can therefore be made from the FWQS data in regard to piggery operations of a certain size, but a distinction between dairy and beef cattle cannot be made from the data collected. Consequently, from the FWQS questionnaire responses, if 24 piggeries with 200 or more pigs were assumed to have liquid storage, the mean NO_3^- concentration of 0.58 (± 0.25) mg/L would be significantly lower than the overall FWQS mean of 2.20 (± 0.28) mg/L. While this is a very simplistic approach to assessing the linkage between liquid animal-waste lagoons and NO_3^- contamination, it helps to eliminate that process from the 46 sites with NO_3^- levels above 10 mg/L at the time of sampling. A closer examination of the 816 sites that have liquid storage located in coarse textured soils might reveal more meaningful results, especially if data reflected the temporal variations noted by Ritter and Chirnside (1987).

In comparison, for all piggeries (84 farms) the mean NO_3^- concentration was 3.28 (± 1.16) mg/L. For the 554 farms with cattle the mean NO_3^- level was 2.26 ± (0.35) mg/L while those with more than 30 head (455 farms) had a mean of 2.53 (± 0.42) mg/L of NO_3^-. The 69 farms with poultry had a mean NO_3^- concentration of 2.4 (± 0.89) mg/L and those operations with 500 birds or more (14 farms) the mean was 0.091 (± 0.043) mg/L of NO_3^-). While subtle differences were noted among the various livestock types, only poultry was significant when assessing sites with flocks over 500 birds. One problem encountered with the above analogies of the FWQS data was that a large number of the farms surveyed had more than one livestock type; therefore, it is not possible to discern which species or combination of species affected NO_3^- concentration most. However, while 75% of the farms had some volume of livestock, there was no significant ($p = 0.720$) relationship observed between livestock in general and nitrate concentration.

Chang and Entz (1996) found that under annual cropping conditions, leaching losses of NO_3^- were minimal in the Dark Brown or Brown soil zones of southern Alberta. Only under significant rainfall conditions within a given growing season was there appreciable NO_3^- movement through the upper soil zone, from beef manure applied at three times the recommended rate. Riddell and Rodvang (1992) found significantly higher NO_3^- concentrations in observation wells in fields with high beef manure application compared to unmanured fields under irrigation. For the FWQS sites, manure application within 50 m of the well was significant but weakly correlated to NO_3^- levels ($p < 0.05$); however, application of manure within 50 m was not significant for wells with NO_3^- levels above 10 mg/L.

3.3.2 Total Coliform Bacteria

In determining practices that may contribute to the presence of total coliform (TC) bacteria, the FWQS questionnaire included a number of related questions which were asked at the time of the water sample collection. Activities related to livestock production and septic systems were viewed as having the greatest potential for bacterial contamination. Livestock production because of the volume and handling of manure is often viewed as a significant contaminant source. Manure storage ($p = 0.673$), feedlot pens ($p = 0.919$), and corrals ($p = 0.109$) less then 50 m from the well head were not significant to TC detection. The application of livestock manure ($p = 0.197$) within 50 m of the wellhead was also not significant to the presence of TC; however, Rudolph and Goss (1993) in Ontario, found this relationship between manure application and coliform detection more significant than was evident in the FWQS data.

Krider (1987) noted that in humans, gastroenteritis is the leading cause of waterborne infectious disease in the United States contracted through deficiencies in water treatment and groundwater contamination. The rate of gastrointestinal illness in the Lethbridge, Alberta region is three times higher than the rest of the province (Hasselback, 1997). This fact is sometimes linked to high livestock numbers; however, no evidence has proven a linkage to

this connection between the illnesses and livestock numbers in southern Alberta. The detection of TC or faecal coliform, which are indicators of other harmful microorganisms, were not significantly greater in southern Alberta; but rather, observed faecal coliform detections in central and northern Alberta were higher than in southern Alberta (Figure 2.6). However, from the FWQS results, having livestock ($r^2 = 0.01$ at $p = 0.005$) was significant but weakly related to the presence of TC in the wells tested.

The general public in Alberta tends to view large livestock operations as having a great potential to cause groundwater contamination. If this is true, then one would expect to find a high level of bacterial and nitrate contamination in well water on site. By examining the FWQS livestock data for those farms with livestock threshold values above the 1995 Code of Practice for the Safe and Economic Handling of Animal Manure (AAFRD, 1995) (Table 3.1), which is currently used in Alberta for permitting certain sized farms; there was no significant relationship between larger herd sizes and the presence of TC bacteria.

The presence of a septic system within 50 m of the well head was not significant ($p = 0.098$) while the age of the septic system was slightly significant ($p = 0.054$) to TC detection. Sharpe et al. (1993) found a significant correlation between septic system age and location in controlling concentrations of NO_3^- and TC bacteria in groundwater wells in Pennsylvania. This correlation was greatest for septic systems within 30 m of the wellhead. The significance indicated by Sharpe et al. (1993) may have been noted in the FWQS data if graduated distance data had been collected at each site rather than a single cut off point of 50 m from the wellhead.

Rudolph and Goss (1993) in Ontario, also found that "bacteria concentrations were not significantly correlated with deeper or older wells, drainage toward the wellhead, presence of animals on the farm, or proximity to septic systems, manure storage areas or feedlots". Again these results concur with those of the FWQS data for TC detections.

3.3.3 Herbicides

The greatest single contributor to herbicide detection may be point source handling errors at or very near the wellhead, as indicated by Frank et al. (1987b). In Ontario, Frank (1981) and Frank et al. (1987a, 1987b, 1990) showed that well water contamination by pesticides is often due to improper practices during application, loading, mixing, and storing of pesticides. In many cases the well had been contaminated directly or by surface runoff rather than by influx of contaminated groundwater into the well (Pupp, 1989). Specific practices which significantly increase the risk of such well contamination include the testing of spray nozzles beside the wellhead, cleaning out of the tank beside the well, or the storage of pesticides in the well house or pump pit.

Few questions of the participants on practices explained the 27 herbicide detections ($\geq$0.05 μg/L). The use of the well water and thereby the mixing of herbicides at the wellhead was not a significant factor affecting herbicide detection. However, comments provided by participants regarding past spills or back-siphoning accidents helped to explain two site contaminations. The use of herbicides within 50 m of the well did not significantly affect herbicide detection. Although, based on the wording of the questions (Appendix B-1), individuals may have only answered in the context of agricultural chemicals, neglecting to include those herbicides used for lawn and garden care which can also be a source of contamination in the immediate area of the well. This however, is not assumed to be the cause of a significant number of the herbicide contaminations. In the determination of which agricultural practices are the most significant to herbicide contamination location, primarily soil conditions and ease of water movement from surface to groundwater are likely the most significant non-point source contributions (Miller et al., 1994; Miller and Lindwall, 1992)

The correlation between herbicide sales by municipality based on active ingredient (Cotton and Brytus, 1995) and change in 1991-1996 Canada Census data (Alberta Agriculture, 1998)

to the locations of the 27 herbicide detections is weak. For the most part, detections were random throughout the province with the exception of the Peace River Region in which no detection occurred.

3.4 Water Well Construction

Steichen et al. (1988) found that "statistical analyses performed ... on as many aspects of the well construction and location as possible ... was adequate for model building only for nitrate". However, the researchers were "unable to determine a strong relationships between nitrate levels and various characteristics of the wells, as indicated by the low value $r^2 = 0.18$". Similarly to the Steichen et al. (1988) study, the FWQS examined a representative number of Alberta farmstead wells to evaluate the level of contamination and the state of water quality being used by farm families. However like Steichen et al. (1988), the problem of having more parameters which affect water quality than can be collected exacerbates the problems of predicting the effects of those collected variables on the NO_3^- concentrations observed. A host of well construction parameters may be correlated to the NO_3^- concentration (Jennings et al., 1991; Richards et al., 1996; Rudolph and Goss, 1992; Sharpe et al., 1993; Stievers and Fulhage, 1992) including well depth and construction methods. While the evaluation in this study did not take into account the extensive Alberta Environmental Protection Groundwater Information Centre Water Well Log Database, which in a more detailed examination might provide a greater degree of specifics related to the construction of each well method, the information provided through the FWQS data can lead to general provincial statements about well water quality and factors affecting it.

3.4.1 Nitrates

Well depth was significantly ($r^2 = 0.04$, $p < 0.001$) correlated with NO_3^- concentration. Forty two percent of the 46 Alberta FWQS well sites that exceeded 10 mg/L had a depth less than 30 m (mean depth= 13.38 (±1.1) m with the mean NO_3^- concentration=26.58 (±3.13) mg\L).

However, 96% of the variance in NO_3^- concentration would be attributed to other factors. Nonetheless, as well depth increased, the concentration of nitrates decreased (Figure 3.3). Furthermore, for the 816 FWQS sites, drilled wells were significant and negatively correlated ($p < 0.001$) while dug wells were significant and positively correlated ($p < 0.001$) to NO_3^- concentration. Therefore, drilled wells (641) which are more often deeper (53.62 ± 1.58 m) had a lower NO_3^- concentration (1.19 ± 0.22 mg/L) in comparison to dug wells (167) which are shallower in depth (16.06 ± 1.07 m) and had a higher NO_3^- concentration (6.10 ± 1.00 mg/L).

From a review of other research (Ecobiochon et al., 1990; Frank et al., 1991; Gosselin et al., 1997; Johnston, 1955; Murphy, 1992; Rudolph and Goss, 1993; Steichen et al., 1988; Swistock et al., 1993) the factors which correlated most significantly to nitrate concentration in well water were depth of the well and method of well construction. From the overall FWQS data, sites with large diameter dug or bored water wells ($p < 0.001$) and drilled wells ($p < 0.001$) were significantly correlated to NO_3^- concentration.

The NO_3^- concentration of the FWQS wells was significant but weakly related to well age ($r^2 = 0.01$ at $p = 0.004$; Figure 3.3). Another significant factor weakly related to NO_3^- level ($r^2 = 0.01$ at $p = 0.004$) was pooling of surface water at or very near the well. Surface water at the well head would clearly increase the chance of contaminants entering the well from sources such as barnyards, fertilized fields or even fertilized lawns surrounding the wellhead. This pathway into the well occurs as a results of a failure in the well seal, annulus, or casing or as a result of poor initial construction.

Other factors related to water well construction, such as old unused wells in close proximity to the well tested or the use of below ground well (pump) pits to house well equipment at the well head are believed to have potential to cause NO_3^- contamination. However, this was not the case with the FWQS data, as neither factor was significant.

3.4.2 Total Coliform Bacteria

Well pump pits and water pooling at the wellhead did not correlate significantly to total coliform (TC) bacteria detection. The relationships between dug wells and TC detections ($r^2 = 0.034$ at $p < 0.001$, Pearson correlation= + 0.174) and between drilled wells and TC detections ($r^2 = 0.033$ at $p < 0.001$, Pearson correlation= - 0.162) are weak but significant. The method of construction; therefore, was a factor as dug wells (which tend to be shallower in depth) and had a significant and positive relationship to TC detection while drilled wells (which tend to be deeper) were also significant but negatively related to TC detection. While more of the TC detections were from drilled wells (68/113) compared to dug wells (44/113), the percentage of dug wells with a TC detections was 2.5 times greater than the percentage of drilled wells (Figure 3.3). Consequently, more TC detections can be expected in dug wells than in drilled wells, based on the FWQS data. Goss et al., (1998) in Ontario also found that bacteria concentrations were significantly correlated with shallower as well as older wells. The FWQS data, however, did not provide evidence of a significant relationship between TC and well age ($p = 0.596$). As noted in Figure 3.3, a rather consistent detection level among equal age categories was observed.

Ecobichon et al. (1990) in New Brunswick and Kross et al. (1992) in Iowa, found that wells <15 m deep tended to be more frequently contaminated. Fifty eight percent of the wells with TC detections were >30 m deep; however, well depth was not significantly correlated ($p = 0.500$) to TC detection. This was also true for faecal coliform bacteria detections. Contamination level over various depths appears random (Figure 3.3), as found by Sheheen (1998) in Saskatchewan. In that study, the Sheheen (1998) observed a 22% detection rate for TC detections in a wide range of wells, from depths of 5 to 430 m, under various aquifer types, and various well construction methods.

Others have provided evidence of seasonal variations in bacteria detection (Ecobichon et al., 1990; Rudolph and Goss, 1993); unfortunately, the FWQS data were not collected

temporally. Therefore, evidence of possible seasonal variation from the Alberta sites is not available.

3.4.3 Herbicides

No significant correlation was found between the construction methods including drilled wells ($p = 0.174$), dug wells ($p = 0.568$), well depth ($p = 0.864$), well age ($p = 0.404$), or the pooling of surface water at the wellhead ($p = 0.193$) for the 27 herbicide detections (Figure 3.3). This random herbicide detection trend differs from that found in other studies, such as Richards et al. (1996), who found from approximately 35,000 water samples collected in the Midwestern United States that concentrations and detections tended to be higher in wells that were shallower, older, dug, located near cropland and chemical mixing sites, and on sandy soils. As well, Goss et al. (1997) in Ontario found shallower, older, dug wells had more detections. Sievers and Fulhage (1992) in Missouri found herbicide detections most strongly correlated to well depth with shallow wells having the greatest number of detections. Frank et al. (1987a) found a 2:1 ratio of herbicide detection in dug wells versus drilled wells. However, the FWQS data indicated that shallow and deep wells, whether dug or drilled, of all ages are equally susceptible to herbicide contamination. Whether the contamination is from point sources (at or very near the well head) or non-point sources entering into sensitive recharge areas is not known from these data. However, point source contamination can likely be ruled out for 25% of the wells that had a herbicide detection, as at these site spray water was not obtained from the well nor were herbicides mixed at these wells.

Herbicide results from 816 well sites were not significantly related to well depth, well construction, well age, or the presence of old wells and subsurface well pump pits and pooling water near the well. The fact that so few detections (3%) were found emphasises the need for more in-depth observation at detection sites over time with a full site evaluation to address and fully substantiate any conclusions on the direct cause of the herbicide detections.

3.5 Relationships Between High Nitrates, Detection of Total Coliform Bacteria and Herbicides to Soil Type, Geologic Conditions, and Eco-region / District Characteristics.

The Agricultural Region of Alberta Soil Inventory Database (AGRASID) Version 1.0 (1998), the National Ecological Framework classification system (Ecological Stratification Working Group; 1995), Contour Map of Aquifer Sensitivity (Golder Associates, 1998), and the Geological map of the Western Canada Sedimentary Basin (Canadian Society of Petroleum Geologists, 1996) were used to identify potential relationships to the nitrate, coliform, and herbicide detections encountered within the FWQS data. These classification systems are on a township scale for AGRASID using 1:1,000,000 data; at a regional scale for the Ecological Stratification Working Group (1995) data at 1:1,000,000; and Western Canada 1:6,000,000 scale for the Geological map (Canadian Society of Petroleum Geologists, 1996) and Contour Map of Aquifer Sensitivity (Golder Associates, 1998) compared specific farm site data recorded on a quarter section scale for the FWQS. Thus, only general relationships can be derived. The intent of this section is to identify general spatial trends by relating these ecological, hydrologic, soil and landscape features to the water quality parameters in question.

3.5.1 Nitrates

Some of the well sites with high nitrate levels were located on coarser materials or under poor drainage conditions. However, most of these sites which exceeded the MAC for nitrate in drinking water were primarily on freely drained Chernozemic soils on medium to fine till or glacial-lacustrine parent materials with a predominately undulating landscape. This description in itself would describe a large portion of the Alberta landscape.

Higher NO_3^- concentration for the FWQS sites were identified in the Southern, Northwestern, and Peace Regions (Figures 3.4). These sites also correspond to the shallower wells, which

typify the locations identified by Golder Associates (1998) as some of the sensitive aquifer areas in Alberta (Figure 3.5). Identifying a sensitive aquifer area is based on the average well depth as determined by Alberta Environmental Protection's Groundwater Information Database which contains water well drilling reports for the province. Shallower water wells are often built to reduce costs or because deeper supplies are of poor quality (ie: high TDS, Na^+, SO_4^-, etc.) or not easily obtainable. Higher NO_3^- concentrations in water samples taken from these shallower wells reflect the concept described in Section 3.4. Shallower wells have a higher potential for NO_3^- contamination as result of natural NO_3^- sources in the shallow surficial materials or as result of a reduced flow pathway or a more direct conduit for surface contamination to reach the aquifer than is typical of deeper wells.

High nitrate levels due to sedimentary nitrogen deposits have been reported in southern Alberta since the turn of the century (Freeze and Cherry, 1979; Hendry et al., 1984; Henry and Meneley, 1993). As a direct result of sod turning and summerfallow agriculture, these nitrogen deposits have mineralized over time allowing NO_3^- leaching to occur. The natural nitrogen deposits within the prairie regions of southern Alberta have been documented by Hendry et al. (1984) and Riddle and Rodvang (1992) and correlate to the southern edges of the moist mixed and fescue grassland Ecoregions.

The higher NO_3^- concentrations detected in Northeastern Alberta and into the Peace River Region are also associated with wells dug into shallow aquifers which have some sensitivity. Some of these shallower wells are located in the Peace Lowlands Ecoregion in the high yielding, unconfined Grimshaw Aquifer. On highly permeable surficial materials with a high transmissivity, like those of the Grimshaw Aquifer, nitrogen fertilizer application or poor septic systems could be important at greater distances from the well than in the central Alberta regions (MacMillan et al., 1997).

Overall, the majority of the FWQS high nitrate detections were found in areas that can be classified as having shallow, sensitive aquifers influenced by local surficial geology or

simply by the effects of faster leaching from surface nitrate sources. Frank et al. (1991) found that study sites in Ontario with higher nitrate concentrations tended to be on sandy loam soils overlying shallow confined aquifers.

3.5.2 Total Coliform Bacteria

The 113 total coliform (TC) detection (TC≥1 colony/100 mL) sites were primarily located on both undulating and hummocky landscapes. Soils at these sites were developed mainly on medium textured tills or fine textured water-laid sediments with approximately 10% developed on gravelly, coarse textured materials. The drainage at these FWQS sites was described as primarily well to moderately well drained with 25% of the sites situated on very poor or poorly drained soils. At least 50% of these sites had hummocky landscapes, were in flood plains, or had water bodies associated with the Ecodistrict and soil polygons in which the well site was located.

Rudolph and Goss (1992) found coliform bacteria contamination in Ontario generally greatest in loamy soils while nitrate detections were greatest in coarser textured soils. This result was also noted for the FWQS data, where a higher number of the TC detection sites were located on loamy soils (CAESA, 1998) as opposed to sites on coarse or fine texture soils.

Both TC detections and TC values greater than 10 colonies / 100 mL exhibited spatial variation or randomness within the Ecoregions (Figure 3.6). The exception to the variability in the detections may be the presence of water in potential recharge areas associated with hummocky or water-related landscapes on medium textured soils which could aid in the transport of bacteria to shallower aquifers or to the wellhead. However, more importance would likely be placed on anthropogenic and well construction problems than the geographic location of the wells as evidenced by the random distribution of detections. Hallberg (1987), from a review of over 16,000 water quality analyses from northeastern Iowa, concluded that

bacterial problems were randomly distributed in relation to geologic setting.

3.5.3 Herbicides

Pupp (1989) noted that groundwater contamination by pesticides seems to be linked almost exclusively to areas where monoculture row crops are grown, with frequent application of pesticides on highly worked and exposed sandy soils or on thin overburden over fractured rock, above shallow water tables with high water usage either from natural precipitation or irrigation or both. The majority of the 27 FWQS sites which had a herbicide detection ($\geq$0.05 μg/L) were located on well drained medium to fine textured tills and glacial-lacustrine parent materials with primarily Chernozemic soils with hummocky landscapes. Features of these sites are quite similar to those at both the high nitrate and TC detection sites. However, one notable difference was the absence of herbicide detections in the Peace Lowland Ecoregion (Figure 3.7) which showed an equal tendency for higher nitrate levels and TC detections. This may relate to water sample collection dates which occurred either too early in the growing season thereby not seeing the affects of spring herbicide application or sample collection later in the growing season which might have missed detections in the Peace Lowland Ecoregion as compared to those regions in southern Alberta.

3.6 Conclusion

Determining whether water quality for any given parameter is affected by natural or anthropogenic factors at a given site is difficult, and this is only increased when samples are taken in as a diverse ecological province as Alberta. However, some clear associations related to high nitrate concentrations, or coliform or herbicide detection from 820 farm sites sampled once over a two-year period can be made to provide meaningful understanding of the contaminant relationships observed.

The presence or distance to potential contaminant sources on the farm was not a significant

factor affecting the overall concentration of the three parameters investigated (nitrates, total coliform, herbicides). To some extent geographic location may impart more significance to the concentrations of nitrates and total coliform detected than is evident, as the most significant re-occurring factor was well depth, which is a factor of landscape.

As found by others, well depth and construction methods were the most significant factors contributing to nitrate levels in the FWQS wells. The fact that movement into a shallower aquifer typically requires less time and that most shallow wells are of a larger diameter with an more often poor surface seals is the most probable cause for contamination, given equal agricultural practice methods. However, drilled wells at shallow depths were also subject to contamination. Manure application within 50 m of the wellhead influenced the concentration of nitrate detected but livestock facilities and manure storage facilities within the 50 m distance did not. However, while 75% of the farms had some volume of livestock, there was no significant relationship observed between livestock and nitrate concentration.

Of the three water quality parameters investigated, only nitrate had a significant relationship to other water quality parameters, such as iron, manganese, sodium, etc. which under greater investigation could lead to better methods of identifying sensitive aquifers based on more than well depth.

The overall randomness of the total coliform detections likely indicates that practices immediately adjacent to the wellhead affect this form of contamination. The potential for contamination is related to whether the well construction is poor or the well seal has failed. It should be further clarified that the samples were collected from a drinking water source and include the influence of the distribution system. This latter influence may also account for a number of detections as treatment with disinfection methods in the well were rare.

More herbicide detections were noted in deeper, drilled wells than shallower, dug wells which may be due to more point source contaminations. The lower number of herbicide

detections in shallower wells may also be due to a surficial geology which reduces movement from non-point sources into the aquifer.

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Table 3.1 **Intensive Livestock Operations - Minimum Size (Code of Practice for the Safe and Economic Handling of Animal Manure (1995)).**

Livestock Type	Threshold No.
Beef Feeders (500 - 1200 lbs)	400
Dairy cows (milking)	All
Piggery (sows farrow to finish)	30
Piggery (sows farrow to wean)	50
Piggery (feeders only)	300
Calves (veal)	100
Horses (PMU)	75
Poultry (broilers)	10000 ft^5
Poultry (breeders)	5000
Poultry (layers)	500
Poultry (turkey broilers)	3000
Sheep (ewes)	650

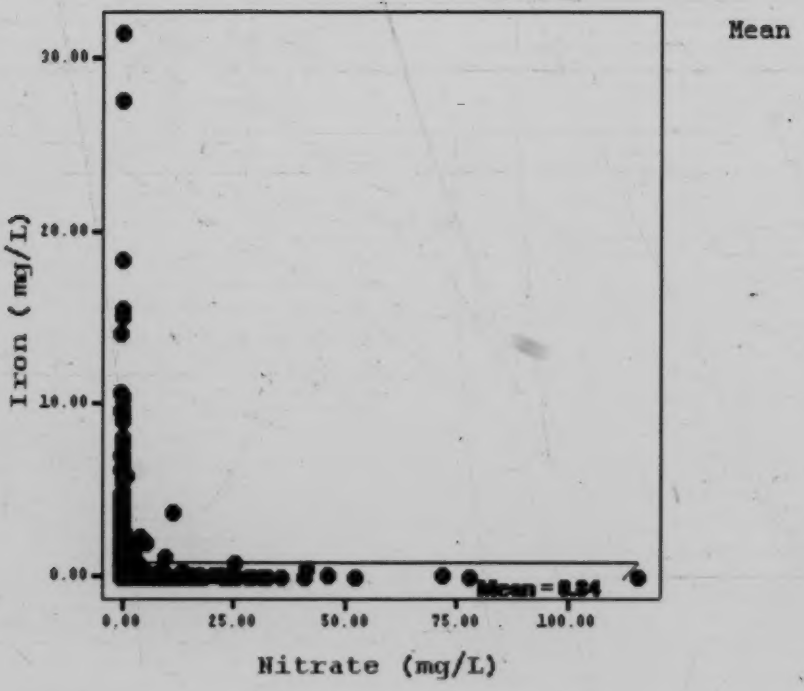


Figure 3.1 Relationship between iron and nitrate from 1995-1996 Farmstead Water Quality Survey results.

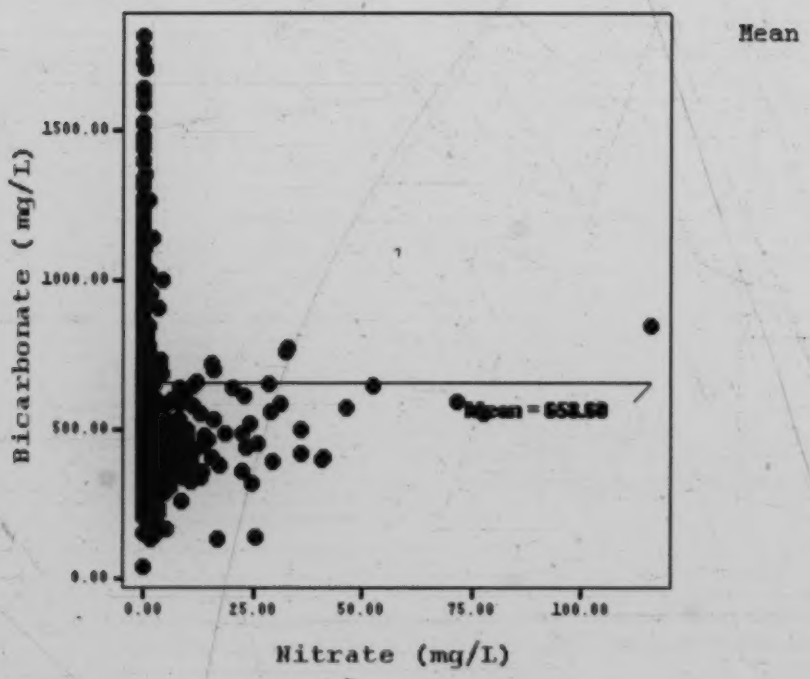


Figure 3.2 Relationship between bicarbonate and nitrate from 1995-1996 Farmstead Water Quality Survey results.

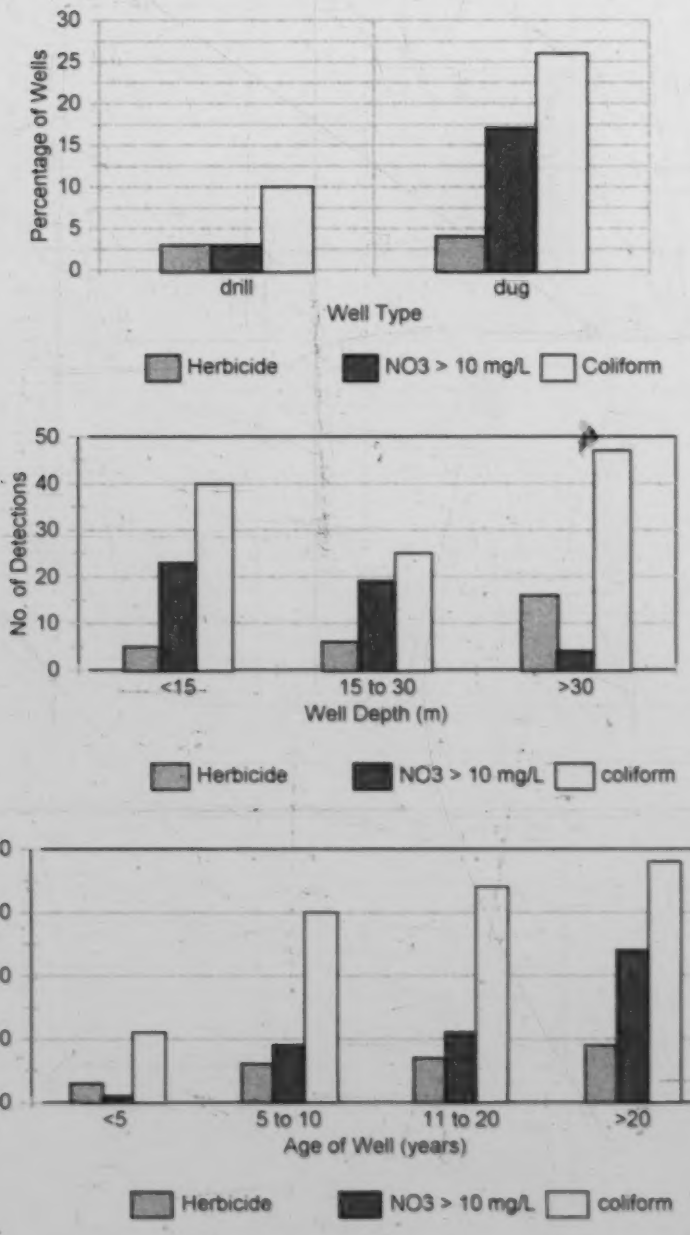


Figure 3.3 Herbicide and total coliform detections, and nitrate concentration >10 mg/L in relationship to well construction method, well depth, and well age from 1995-1996 Farmstead Water Quality Survey results.

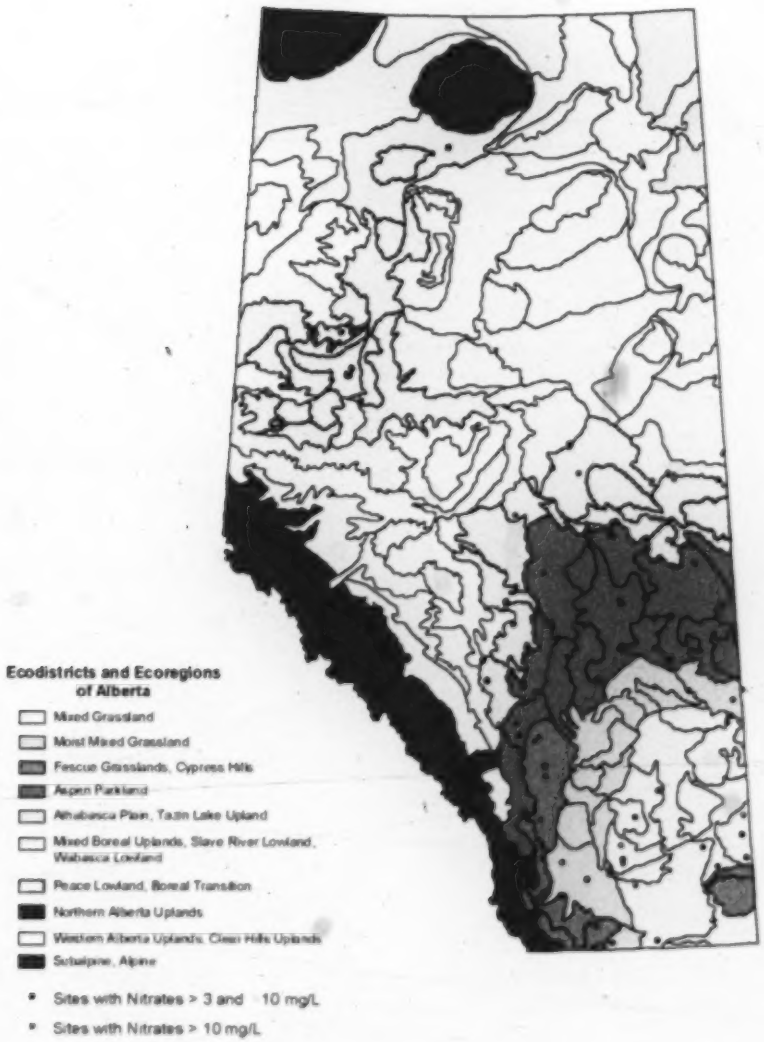

Ecodistricts and Ecoregions of Alberta
Mixed Grassland
Moist Mixed Grassland
Fescue Grasslands, Cypress Hills
Aspen Parkland
Athabasca Plain, Tazin Lake Upland
Mixed Boreal Uplands, Slave River Lowland, Wabasca Lowland
Peace Lowland, Boreal Transition
Northern Alberta Uplands
Western Alberta Uplands, Clear Hills Uplands
Subalpine, Alpine
Sites with Nitrates > 3 and 10 mg/L
Sites with Nitrates > 10 mg/L

Figure 3.4 Nitrate detections > 3 mg/L from 1995-1996 Farmstead Water Quality Survey results by Ecoregion.

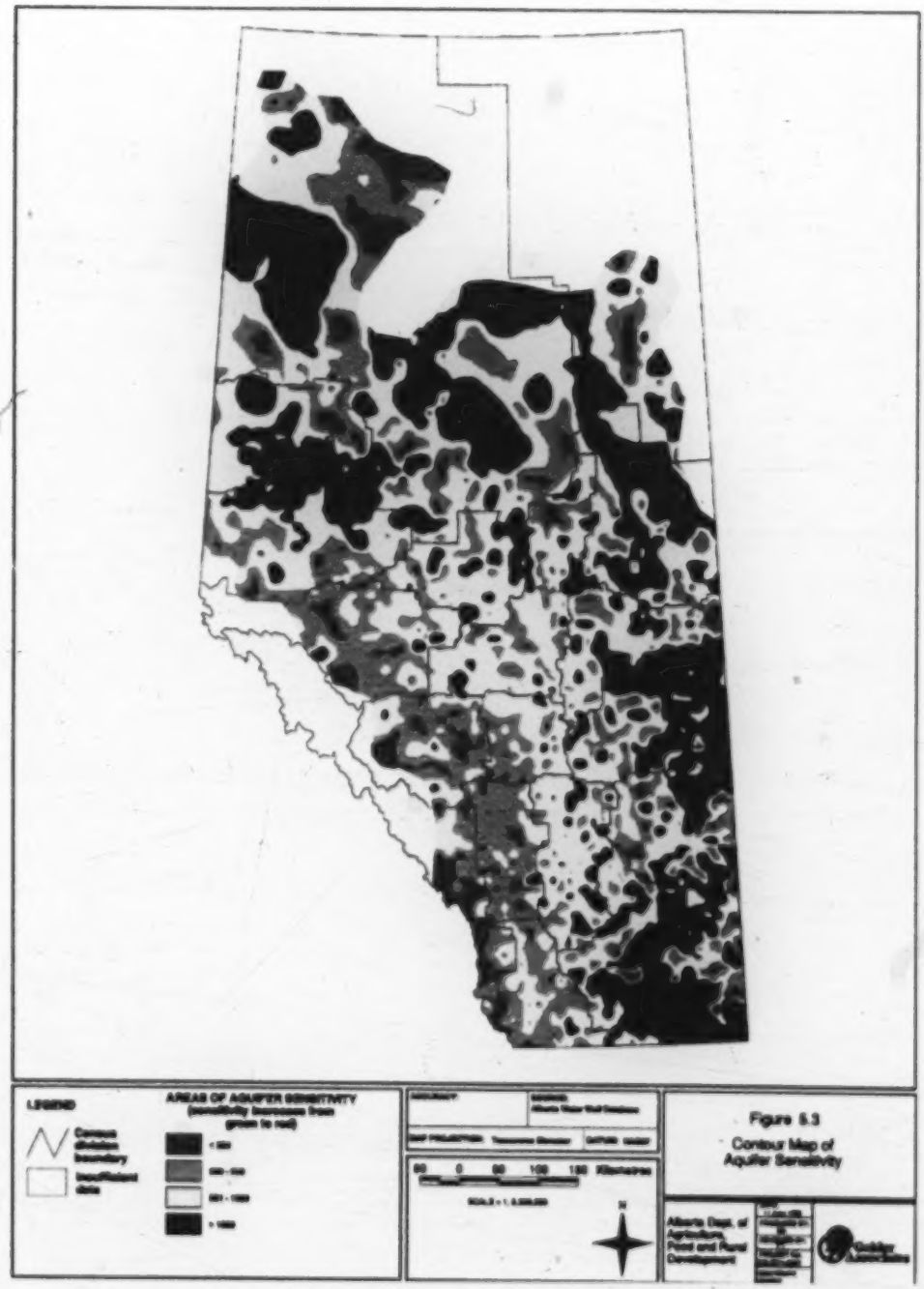


Figure 3.5 Contour map of aquifer sensitivity areas in Alberta.

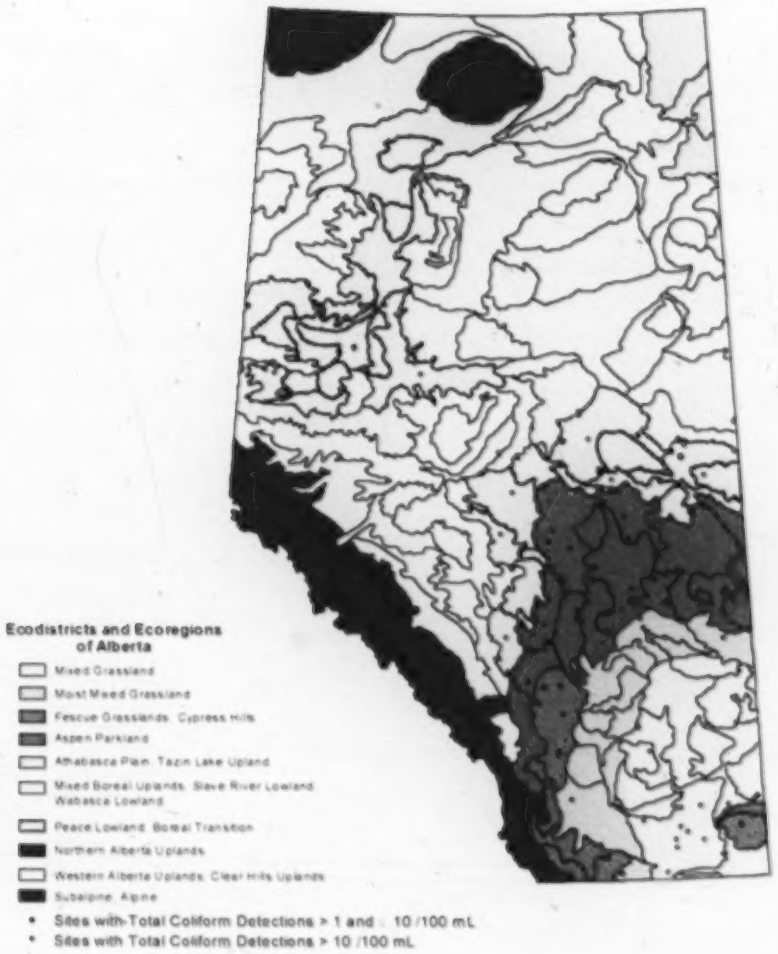

Ecodistricts and Ecoregions of Alberta
Mixed Grassland
Moist Mixed Grassland
Fescue Grasslands, Cypress Hills
Aspen Parkland
Athabasca Plain, Tazin Lake Upland
Mixed Boreal Uplands, Slave River Lowland, Wabasca Lowland
Peace Lowland, Boreal Transition
Northern Alberta Uplands
Western Alberta Uplands, Clear Hills Uplands
Subalpine, Alpine
Sites with Total Coliform Detections > 1 and ≤ 10 /100 mL
Sites with Total Coliform Detections > 10 /100 mL

Figure 3.6 Total coliform bacteria detections from 1995-1996 Farmstead Water Quality Survey results by Ecoregion.

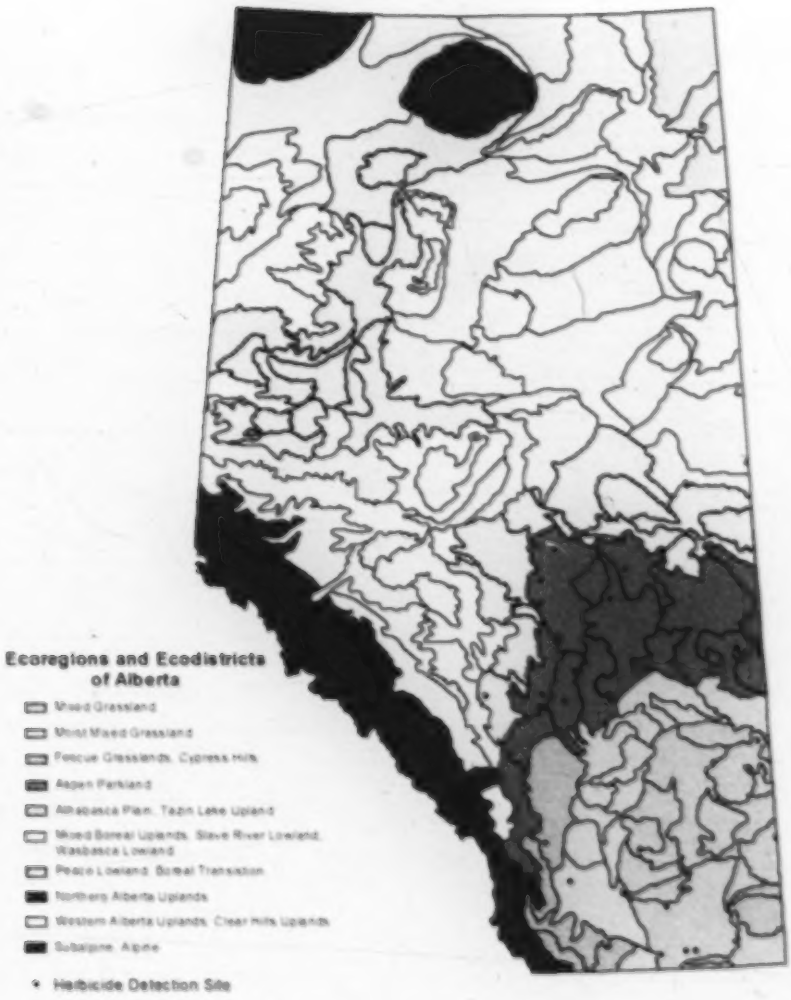


Figure 3.7 Herbicide detections from 1995-1996 Farmstead Water Quality Survey results by Ecoregion.

Chapter 4. Synthesis Of The Alberta Farmstead Water Quality Survey And Rural Water Quality Findings

4.1 Introduction

The purpose of collecting a representative number of groundwater derived water samples from farms across Alberta through the Farmstead Water Quality Survey (FWQS) was to determine for benchmark purposes, the suitability of on-farm drinking water. A second objective was to identify impacts of primary agriculture and natural conditions on water quality. This study has identified some key water quality concerns more or less related to natural conditions as well as some related to well construction and agricultural practice.

A study such as the FWQS is often judged by its contribution to a better understanding of the science of groundwater and human actives which impact water quality. However, the significance of the FWQS is far greater in that the inter-agency barriers to information flow were exposed and a cooperative environment that truly helps to solve groundwater issues was fostered by the study. A representative farm water quality database with approximately 950 groundwater and surface supplies is now available to facilitate more detailed studies.

4.2 Implications

The significance of well depth, construction, and age to detectable nitrate concentrations may typify the sleeping giant related to most groundwater quality problems in Alberta. The complacency of most well owners on issues of maintaining and understanding their water supply compounds any water quality problem. Maintenance and understanding of water wells, understanding the effects of surface practices on water quality, or simply understanding what constitutes a well constructed water well all help to decrease the

potential for water quality problems.

Often natural geological conditions effecting water quality go unnoticed by the farm families consuming the water. In other cases, the water problems are due to activities near the well, such as herbicide mixing. The FWQS identified many natural conditions that pose a significant health concern for the water users. Through the cooperative efforts of a multi-agency data collection team, many of these problems have been identified but require further investigation. While statistics employed in the FWQS may not have point to solid cause and effect relationships, the evidence found elsewhere should be considered before making broad statements regarding the current conditions observed in Alberta.

Missing from the FWQS database are details related to soil, geology, and direct well construction, questions that may have added more information on contaminant levels or temporal sampling which might have identified the possible seasonal variability found in other provinces and states. However, these data and some of the observations made will help to develop a long-term Alberta groundwater monitoring program under the Alberta Environmentally Sustainable Agriculture Program. This project has also helped to make governments more aware of the need for public access to water quality testing and the need for agencies to share water quality data in order to gain a better understanding of the issues related to water quality.

4.3 Recommendations

Cooperative efforts amongst municipal, provincial and federal agencies in collecting and interpreting results via a provincial groundwater monitoring program at the drinking water level would be very beneficial to all. The cost of conducting studies such as the FWQS would be better serviced with well user financial support and voluntary data collection and submission.

Identifying the contaminant areas in the province through the FWQS also requires follow-up to thoroughly address the causes to the effects observed in order to provide more focussed efforts on the areas of the province where contamination may be most severe or practices that may cause significant problems. Identifying areas of the province in which naturally occurring contamination occurs is also needed to safe guard public health. A significant number of those who participated in the FWQS had never tested their water or had no knowledge of water quality testing. However, for those who may have tested their water, routine potability testing would not measure arsenic, selenium, or uranium concentrations. The trace metal testing conducted under the FWQS also identified situations that can most likely be attributed to distribution system contamination of the water supply at the tap.

Increased education and awareness about contamination problems associated with shallow wells and the method of construction which can be severely impacted by certain activities or parameters (i.e. nitrates) are needed. This can be accomplished through follow-up on the FWQS sites or through the new Alberta Water Act groundwater licencing process which will affect the vast majority of farm operations which will be required to register farm wells. A multi-agency approach to sampling along with education and awareness could benefit to groundwater users.

Finally, measurements not made during the FWQS such as exact distances to potential contaminant sources, collection of the specific well construction data and measurement of water table levels, identifying land-use factors outside the immediate farmstead site, and the collection of temporal samples are all factors which should not be neglected in future groundwater surveys or monitoring programs. The extra effort required to obtain these pieces of information will justify the resource requirements by providing a more complete database upon which to make interpretations and recommendations.

4.4 Future Research Needs

Follow-up on the FWQS sites that had herbicide detections and nitrate concentrations greater than 10 mg/L would be beneficial to the overall understanding of the processes involved that caused the effects observed. Similarly, more research and monitoring of high arsenic and uranium sites found through the FWQS results along with areas surrounding these sites would help to delineate the extent of the problem locally. As well, many of the exceeded aesthetic objectives occurred in combinations from which health related factors may become more apparent with a boarder multi-disciplinary approach to addressing these types of water quality problems.

Many other possible research efforts including chemical and biological processes, well construction, and farm practices related to groundwater quality exist from the benchmark data collected through the FWQS. By continuing the cooperative approach undertaken with the FWQS and through the sharing of knowledge obtained from this project, it is hoped, that future research will be aided and that research will ultimately benefit those farm families who rely on the water beneath them.

Appendices

Municipaity	Area (ha)	Total Farm Population	Total # of Farms	% Alberta Farms
Red Deer Cty.	378523	5320	1795	3
Mountain View Cty.	389596	5390	1784	3
Leduc Cty.	231627	4930	1595	3
Grande Prairie Cty.	465302	4780	1526	3
Rocky View Cty.	406119	4685	1524	3
Camrose Cty	338224	4415	1419	2
Vermilion River Cty.	568866	4380	1412	2
Wetaskiwin Cty.	271720	4005	1352	2
Ponoka Cty.	256904	4165	1332	2
Lacombe Cty.	271200	4365	1327	2
Foothills Cty.	361526	3920	1312	2
Clearwater M.D.	284748	3815	1227	2
Lac Ste. Anne	241152	3620	1200	2
Lethbridge	307106	4235	1188	2
Lamont	222246	2850	1152	2
Sturgeon	206824	3570	1150	2
Parkland	196486	3525	1145	2
Westlock	268755	3515	1120	2
I.D. 17	377391	3040	1049	2
Beaver Cty.	305419	2995	1035	2
Cyprus M.D.	973431	2730	1004	2
Flagstaff Cty.	406711	3045	996	2
Barrhead M.D.	212659	3220	993	2
Kneehill M.D.	354393	3130	989	2
Athabasca Cty.	268957	2785	985	2

Appendix A.1 Alberta farm population and farm numbers by municipality (data from Census Canada, 1991).

Municipality	Area (ha)	Total Farm Population	Total # of Farms	% Alberta Farms
St. Paul Cty.	321808	3065	953	2
Wheatland Cty.	448489	3040	953	2
Taber M.D.	392048	3045	952	2
Newell Cty.	571310	3010	933	2
Stettler Cty.	394028	2815	907	2
Strathcona Cty.	93917	2880	889	2
ID 16	286019	2785	880	2
Minburn Cty.	290988	2625	878	2
Willow Creek M.D.	451623	2810	863	2
Vulcan Cty.	527035	2900	855	1
Two Hills Cty.	232999	2085	807	1
ID 18	287672	2690	785	1
ID 14	190031	2485	782	1
ID 22	275696	2095	765	1
Forty Mile Cty.	731684	2405	748	1
Cardston M.D.	381311	2955	710	1
Thorhild Cty.	153966	1900	691	1
ID 20	245423	1975	689	1
Smoky Lake Cty.	197470	1860	672	1
ID 23	230629	2905	670	1
Bonnyville M.D.	185693	2045	657	1
Special Area 3	714192	1835	650	1
Wainwright M.D.	339219	2120	650	1
ID 21	247879	1960	622	1
Brazeau M.D.	106069	1870	619	1

Appendix A.1 Alberta farm population and farm numbers by municipality (data from Census Canada, 1991).

Municipaity	Area (ha)	Total Farm Population	Total # of Farms	% Alberta Farms
Warner Cty.	451432	2275	607	1
Smoky River M.D.	235011	1805	597	1
Special Area 2	885363	1870	571	1
Provost M.D.	373104	1705	563	1
Paintearth Cty.	308316	1570	525	1
Pincher Creek M.D.	229309	1580	499	1
Starland M.D.	245521	1325	462	1
ID 19	196329	1040	384	1
Special Area 4	430564	1125	364	1
Fairview M.D.	130661	980	342	1
ID 15	85278	1015	327	1
Peace M.D.	94326	730	254	0
Edmonton	26537	610	204	0
Spirit River M.D.	75727	520	195	0
Calgary	7123	105	40	0
Alberta	**20811002**	**177185**	**57245**	**100**

Appendix A.1 Alberta farm population and farm numbers by municipality (data from Census Canada, 1991).

Alberta Farmstead Water Quality Survey Questionnaire

(1996 Survey)

Canada - Alberta
Environmentally Sustainable
Agriculture Agreement

"Agriculture - building a Healthy Environment"

Canada

CAESA

Alberta

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

CAESA
Alberta Farmstead Water Quality Survey
Cooperator's Agreement

Purpose

We are conducting this survey to assess the quality of water being used on farms in Alberta. The survey will be used to develop water quality information, programs, and services for farmers.

Background

The survey includes the testing of farm water supplies for bacteria and chemicals, and the collection of information on factors which could affect farm water quality. The survey is being jointly conducted by the departments of Alberta Agriculture, Food and Rural Development; Alberta Health; the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture and Agri-Food Canada; and your local Regional Health Authority. The survey is being funded under the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement and Alberta Health.

Participants Benefits

Farm water users who complete the attached survey and provide water samples will have their water tested free of charge. Test results will be sent to all participants through the local Regional Health Authority. We will also immediately notify participants if the quality of their water does not meet criteria recommended to protect human health.

Survey Uses

We will use the survey results to report on the quality of water being used on Alberta farms. We will compile the results and use them to assess factors that could put farm families and livestock at risk. We will also use the survey results to develop educational pamphlets, and other measures, which will promote safe, affordable water quality treatment on farms in Alberta. Test results from individual farms are confidential and will only be released to the sample submitter.

Survey participants are asked to sign this cooperator's agreement indicating:

1. that they will allow water samples to be taken on their farm;
2. that they will complete the attached survey; and
3. that they will allow water quality test results, provided to them at no cost, to be compiled and published in CAESA study reports. (Please note that individual water quality test results are confidential and will not be published).

_____ _____ Phone: _____
Cooperator's Signature Surveyor's Signature

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

Alberta Farmstead Water Quality Survey

Date.	Place Label Here
____/____/____ (Day / Month / Year)	FWQS No.

1. Participant's Mailing Address

Sample Identification Numbers

Name:		Chemical #:
Address:		Trace Metal #:
		Microbiological #:
Postal Code:	Phone:	Pesticide #: FWQS

2. Water Source Location

County or Municipal District of:				
Quarter:	Section:	Township:	Range:	Meridian: W of ___

3. Water Source Information (Check boxes which apply to the water which will be tested.)

☐ a) **Well:** Dug/bored *153* Drilled *592* Sandpoint *11*
Screen *66* Slotted casing *156*

Approximate well depth: _____ m **OR** *147 ft.* (Average)
diameter: _____ cm **OR** _____ in.

Approximate age of well: *20 years*. (Average)

Is more than one well connected in combination to form this water source? *Yes 85*

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

4. Water Use Information

a) Please provide the following water use information for your house and farm.

Number of residents: *2877*
Type of farm operation (i.e.: grain *82*, livestock *118*, mixed *501*, other *69*)
Average number of livestock watered: Hogs *(Yes 83 - total 23,030)* Cattle *(Yes 552 - total 103,148)* Sheep *(Yes 22 - total 3902)* Horses *(Yes 142 - total 2191)* Poultry *(Yes 72 - total 228,158)* Other (specify) *(Yes 175)*
Is the water source being tested used for household needs: *Yes 775*
Is the water source being tested used for drinking water needs: *Yes 691*
If no, what is your source of drinking water: _____
Is the water source being tested used for livestock watering: *Yes 484*
Is the water source being tested used for: herbicide spray water *Yes 230*
insecticide spray water *Yes 3*
If yes, what types of herbicides or insecticides do you use: _____

b) Do you have access to other sources of water within the farmyard or on adjacent land.
Yes 553

Dugouts:

Depth (ft)	Volume (gal)	Size ___ x ___ (ft)	Qtr	Sect	Twsp	Rge	Meridian W of ___	Is this source connected to the sample source?
								Yes ☐ No ☐
								Yes ☐ No ☐
								Yes ☐ No ☐
								Yes ☐ No ☐

Wells:

Depth (ft)	Diameter- (in)	Age (yr)	Well pit (yes/no)	Actively used (yes/no)	Qtr	Sect	Twsp	Rge	Meridian W of __	Is this source connected to the sample source?
										Yes ☐ No ☐
										Yes ☐ No ☐
										Yes ☐ No ☐

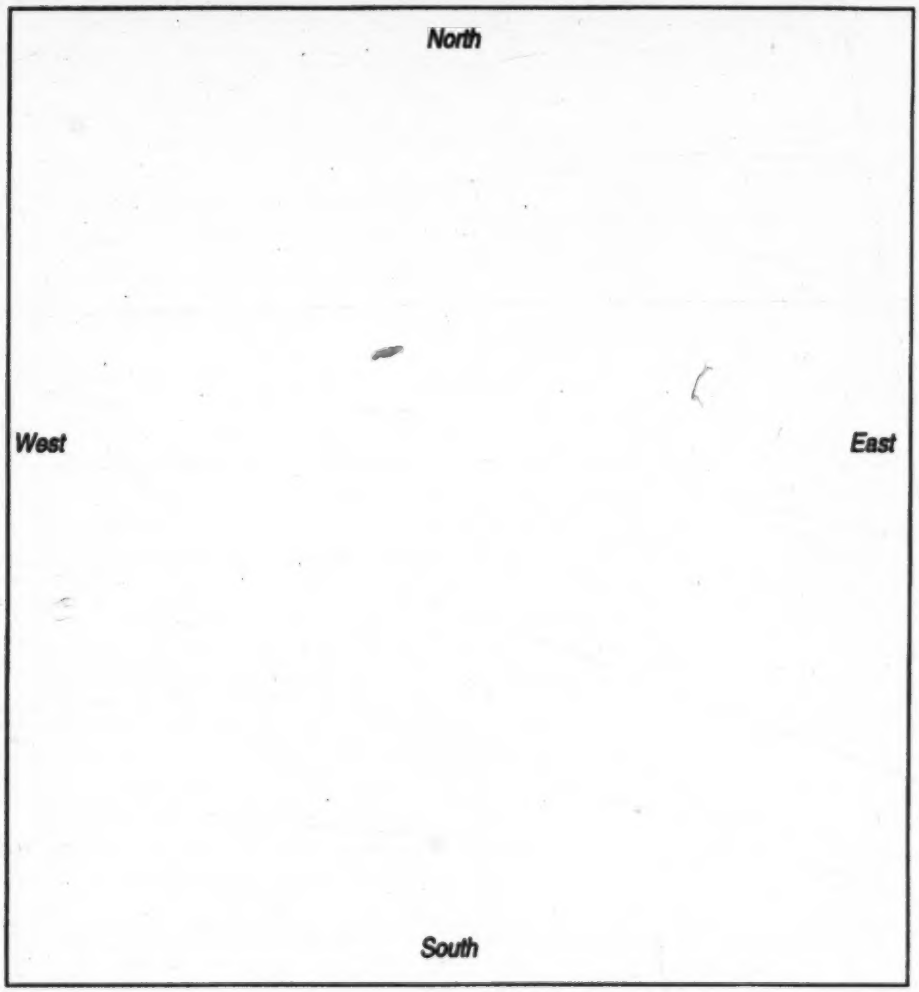
Other Sources:
Creek *89* River *19* Lake *15* Haul water *25* Name of source _____
Spring *34* Pipeline *4* Irrigation Canal *7* Name of irrigation district _____

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

5. Water Sampling Location

In the space below, sketch the farmstead water system. Please add any other information you feel is relevant and helpful. Include the locations of wells, dugouts, pipelines, buildings, livestock facilities, lagoons, sewage systems, etc.

MARK THE LOCATION WHERE THE WATER SAMPLE WAS TAKEN WITH AN "X".



Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

6. Well Information

Please answer the following farm well questions to the best of your ability.

a) Is the well located in a subsurface "well pit"? *Yes 258* No □

b) Does the well head have a waterproof seal or cap? *Yes 600* No □

c) Does a hydrant drain back into the well or well pit? *Yes 117* No □

d) Are hose couplings fitted with back-flow prevention devices? *Yes 285* No □

e) Do you have any wells that are no longer actively used? *Yes 357* No □ (if no, go to (i))

f) If yes, how many wells are no longer actively used? (*Total 517*)

g) If yes, have they been properly sealed or plugged with bentonite or concrete to prevent groundwater contamination? *Yes 59* No □

h) If yes, was the well plugged by a licensed driller? *Yes 0* No □ Don't Know □

i) Does surface water collect or pond near the well? *Yes 49* No □

j) Is the well located less than 50 metres (150 feet) from a septic field or sewage lagoon? *Yes 177* No □

k) What is the age of your septic or sewage system? (*Average 18 years*)

l) Is the well located less than 50 metres (150 feet) from fuel storage tanks? *Yes 151* No □

m) Have petroleum products been drained or spilt on the ground with in 50 metres (150 feet) of the well? *Yes 42* No □

n) Are any of the following located less than 50 metres (150 feet) from the well?
i) corrals....*Yes 223* No □ ii) feedlot....*Yes 67* No □ iii) manure storage....*Yes 33* No □
land which iv) pesticides are applied.... *Yes 51* No □
v) fertilizers are applied.... *Yes 69* No □
vi) manure is applied.... *Yes 42* No □

o) Have you done any of the following to improve your well water quality.

□ Treated well with chlorine (bleach) for bacteria. (*Yes 174*)
□ Shock chlorinated for iron bacteria. (*Yes 170*)
□ Drilled a new well or deepened an existing well. (*Yes 86*)
□ Other (please specify). (*Yes 81*)

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

c) How often do water quality problems occur on your farm? (Check ONE of the statements below)

629 □ Seldom. Usually no water quality problems.
79 □ Occasionally or seasonal water quality problems.
70 □ Frequently. Water quality is a continuing problem.

d) Which of the following potential sources of contamination could be a threat to your farm wate supply source? (Check ONLY THOSE that apply to the source tested!)

168 □ Livestock/manure disposal.
148 □ Pesticides (herbicides or insecticides) applied on fields.
106 □ Fertilizers applied on field.
142 □ Septic field effluent or septic tank leaks.
4 □ Other unused or abandoned wells.
70 □ Petroleum products (gas or oil) spills
10 □ Wildlife (beaver, muskrat, ducks, etc.)
263 □ Oil and gas well drilling/extraction.
35 □ Municipal or industrial wastes.
47 □ Herbicide tank mixing/washing operations.
51 □ Flooding (high spring runoff/rainfall events).
65 □ Other sources (describe briefly) _____

_____

9. Water Testing Information

a) Have you ever had your water quality tested *Yes 671* □ No (if no, go to Question No. 10)

If yes:
273 □ When the well was drilled
38 □ More than once in the last year
20 □ Once in the last year
281 □ Once in the last five years
54 □ Don't know

b) Why did you test your water quality? (Check ALL THOSE that apply!)
563 □ For human health reasons (safety of drinking water)
171 □ For water treatment reasons (i.e. to see if treatment equipment works).
86 □ For agricultural purposes (livestock watering/production)
16 □ To see if "spills" or "pollution" contaminated the source of water (i.e. fuels, pesticides, or sewage).

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

or sewage).

10. Would you be willing to participate in other public health or environmental farm-based studies conducted in the future by:

a) Alberta Health? *Yes 690* ☐ No
b) Agriculture Departments? *Yes 698* ☐ No

11. Do you have any comments which you feel are essential that you would like to add?

_____
_____
_____
_____
_____

Thank you for completing this questionnaire!

Appendix B.1 Alberta Farmstead Water Quality Survey questionnaire.

university of Alberta hospitals

Trace Elements/Environmental Toxicology Laboratory

Department of Laboratory Medicine and Pathology
8440 - 112th Street, Edmonton, Alberta T6G 2B7
Laboratory (403) 492 - 8653

Report to

CHINOOK REGIONAL HEALTH AUTHORITY
LETHBRIDGE, Alberta
T1J 4L5

Req. ID No: N298274
UAH LAB No: 200012538

PRIVATE DRINKING WATER From

Other, Joe
Somewhere AB
T1T 1T1 333-7777
Land Description: SW-36-36-36-W6
Collected: 26 June 1995
by: Sam
Site: KITCHEN TAP
Source: WELL
Depth: 80 Feet
Comments: CAESA FWQS1042
TM N298273

Certificate of Chemical Analysis

			CDW Guidelines(1993)
Conductivity	1700	uS/cm	
Sodium	97	mg/L	< 200 mg/L AO
Potassium	4.8	mg/L	
Calcium	174	mg/L	
Magnesium	101	mg/L	
Hardness, Total (CaCO3)	850	mg/L	
Iron	0.03	mg/L	< 0.3 mg/L AO
Total Alkalinity (CaCO3)	417	mg/L	
Carbonate	0	mg/L	
Bicarbonate	508	mg/L	
Hydroxide	0	mg/L	
Chloride	69.9	mg/L	< 250 mg/L AO
Fluoride	0.13	mg/L	< 1.5 mg/L MAC
Nitrate + Nitrite (N)	36.00	mg/L	< 10.0 mg/L MAC
Sulphate	455	mg/L	< 500 mg/L AO
Total Dissolved Solids (calc)	1311	mg/L	< 500 mg/L AO
Cation Sum	21.34	mEq/L	
Anion Sum	22.35	mEq/L	
Ion Balance (Cation/Anion)	0.95		
Ion Balance (% Difference)	-2.31		

Comments:

Received: 27 June 1995
Reported: 06 July 1995

CDW = Canadian Drinking Water
AO = Aesthetic Objectives
MAC = Max Acceptable Conc.

Certified by:

For Dr. Robert J. Audette, FCIC
Section Head, Clinical Biochemist
Trace Elements/Environmental Toxicology
(403) 492-6648

Appendix B.2 Certificate of chemical analysis (routine chemistry).

university of Alberta hospitals

Trace Elements/Environmental Toxicology Laboratory

Department of Laboratory Medicine and Pathology
8440 - 112th Street, Edmonton, Alberta T6G 2B7
Laboratory (403) 492 - 8653

Report to

CHINOOK REGIONAL HEALTH AUTHORITY
LETHBRIDGE, Alberta
T1J 4L5

Req. ID No: N298273
UAH LAB No: 200012545

PRIVATE DRINKING WATER From

Other, Joe
Somewhere AB
T1T 1T1 333-7777
Land Description: SW-36-36-36-W6
Collected: 26 June 1995
by: Sam
Site: KITCHEN TAP
Source: WELL
Depth: 80 Feet
Comments: CAESA FWQS1042
RC N298274

Certificate of Chemical Analysis

				CDW Guidelines(1993)	
Aluminum		6	ug/L		
Antimony	<	1	ug/L		
Arsenic	<	1	ug/L	25	ug/L MAC
Barium		30	ug/L	1000	ug/L MAC
Beryllium	<	1	ug/L		
Boron		140	ug/L	5000	ug/L MAC
Cadmium	<	1	ug/L	5	ug/L MAC
Chromium		5	ug/L	50	ug/L MAC
Cobalt	<	1	ug/L		
Copper		150	ug/L	1000	ug/L AO
Iron	<	20	ug/L	300	ug/L AO
Lead		3	ug/L	10	ug/L AO
Manganese		1	ug/L	50	ug/L AO
Molybdenum		2	ug/L		
Nickel	<	1	ug/L		
Selenium		7	ug/L	10	ug/L MAC
Silver	<	1	ug/L		
Thallium	<	1	ug/L		
Titanium	<	1	ug/L		
Vanadium	<	1	ug/L		
Zinc		35	ug/L	5000	ug/L MAC

Comments:
Received: 27 June 1995
Reported: 06 July 1995

CDW = Canadian Drinking Water
AO = Aesthetic Objectives
MAC = Max Acceptable Conc.

Certified by:

For Dr. Robert J. Audette, FCIC
Section Head, Clinical Biochemist
Trace Elements/Environmental Toxicology
(403) 492-6648

Appendix B.3 Certificate of chemical analysis (trace metals)

Provincial Laboratory of Public Health
University of Alberta
Edmonton, Alberta T6G 2J2
Telephone: (403) 492 8911
FAX: (403) 492 8984

university of alberta hospitals

Medical Microbiology Laboratory
Division of Clinical Microbiology
University of Alberta Hospitals
Edmonton, Alberta T6G 2B7
Telephone: (403) 492 4134

REPORT DESTINATION FITZGERALD, DARCY ALBERTA AGRICULTURE Engineering Services Branch 201 J.G. O'Donoghue Building 7000 - 113th Street EDMONTON, ALTA	**Other Joe** **Somewhere AB** **T1T 1T1** **Tel: (403) 333-777** **Land Descr: SW-36-36-36-W6** **Access #: ID #: N298274**
Copy to: CHINOOK REGIONAL HEALTH AUTHORITY LETHBRIDGE, ALTA T1J 4L5	Lab Spec #: E95RD000884 Sample: PRIVATE DW Coll Site: KITCHEN TAP Source: WELL Fr.Cl: Tot.Cl: pH: Temp: Address: City/Prov: Date Coll'd: 26/6/95 0900 Ph:

Received: 27/6/95 0914
Report Date: 28/6/95

Final Results

COUNT (PER 100 ML)	TOTAL COLIFORMS	LESS THAN	1
	FAECAL COLIFORMS	LESS THAN	1

This test was performed by the membrane filtration method.

Specimen Comments:

Reason (s) for sampling:
CAESA

User's Remarks

FWQS 1042
TM N298273

Appendix B.4 Certificate of microbiological analysis

CAESA Canada - Alberta Environmentally Sustainable Agriculture Agreement

Farmstead Water Quality Survey
Herbicide Results

July 20, 1996

Joe Other
Somewhere, Alberta
T1T 1T1

FWQS No.1042
Chemical Sample No. N298274
Trace Metal Sample No. N298273
Microbiological Sample No. N298274
Herbicide Sample No. FWQS1042

The following herbicide results were found from tests conducted on a water sample collected at land location **SW-36-36-36-W6** on **26/06/96.**

Herbicide Analyzed	Trade Name(s)	Results	Canadian Drinking Water Guidelines MAC (µg/l)
Dicamba	Banvel / Dycleer	N.D.	120
MCPA	MCPA	N.D.	10*#
2,4 - D	2,4 - D	N.D.	100
Bromoxynil	Buctril M / Partner	N.D.	5
Fenoxaprop	Puma / Excel-Super	N.D.	#
Diclofop-methyl	Hoegrass-284	N.D.	9
Trifluralin	Treflan	N.D.	45 (IMAC)
Triallate	Avadex	N.D.	230

N.D. • not detectable above 0.05 µg/l (except Fenoxaprop at 0.10 µg/l).
MAC • maximum acceptable concentrations have been established for certain substances that are known or suspected to cause adverse health effects. They have been derived to safegaurd health on the basis of lifelong consumption. However, water of higher quality may be required for some special purposes, including renal dialysis (Health and Welfare Canada).
IMAC • interim maximum acceptable concentrations as insufficient toxicological data is available to derive a maximum acceptable concentration with reasonable certainty; therefore, interim values have been recommended (Health and Welfare Canada).
* • from the U.S. Environmental Protection Agency (1990).
# • there is no recommended guidelines at this time from Health and Welfare Canada.
µg/l • microgram per litre or one part per billion is an extremely tiny amount. It can be equated to 1 penny in $10,000,000.

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Alberta

Appendix B.5 Certificate of herbicide analysis

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	TDS, CO, FE, K, CL, MG, HCO, CA, SO, TA, NA[a]		Enter

a. All requested variables entered.

b. Dependent Variable: TN

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.911[a]	.829	.827	3.2789

a. Predictors: (Constant), TDS, CO, FE, K, CL, MG, HCO, CA, SO, TA, NA

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	41953.197	11	3813.927	354.743	.000[a]
	Residual	8643.985	804	10.751		
	Total	50597.181	815			

a. Predictors: (Constant), TDS, CO, FE, K, CL, MG, HCO, CA, SO, TA, NA

b. Dependent Variable: TN

Appendix C.1 Multiple linear regression model for nitrate (SPSS Base 8.0)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.370	.365		-1.015	.311
	NA	-.218	.010	-7.506	-21.145	.000
	K	-9.075E-02	.023	-.077	-3.981	.000
	CA	-.226	.012	-2.221	-19.063	.000
	MG	-.230	.018	-1.080	-12.448	.000
	FE	-.399	.054	-.117	-7.430	.000
	TA	-1.892E-02	.006	-.532	-2.998	.003
	CO	-.104	.013	-.156	-8.032	.000
	HCO	-5.487E-02	.005	-1.845	-10.237	.000
	CL	-.147	.004	-3.865	-37.763	.000
	SO	-.156	.003	-7.811	-45.494	.000
	TDS	.176	.004	16.004	39.702	.000

a. Dependent Variable: TN

Appendix C.1 Multiple linear regression model for nitrate (SPSS Base 8.0)